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LIGHT EXPERIMENTS

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Gilbert
Light Experiments
FOR BOYS

BY

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Foreword

The things that are the most common are often the ones that people know the least about. This is true of light. Few boys have even taken the trouble to get the essential facts about this subject. You can realize how important it is when you are told that without the sun — our main source of light — there would be no life at all. There would be no growth of plants, that's sure. I know as a boy my curiosity was always prompting me to ask questions. I wanted to know the facts and reasons for everything. I believe most boys are the same in that respect.

This book has been written so that you can get information first hand on a mighty interesting subject. It is in plain language, which you can readily understand, and a study of it will soon make you familiar with great scientists, who have made laws of great importance. Their discoveries make possible the use of a number of instruments that you know so well. The telescope — the opera glass — the moving-picture machine — are just a few which can be mentioned, and you know how necessary they are in the world to-day.

In learning facts about light and some of the inventions made by great men you will get a knowledge that very few boys have. You will be able to talk very interestingly about light and it will be easy for you to explain a great many questions that come up in connection with it. Best of all, you will have a whole pile of fun and at the same time get a good understanding of the fundamentals of the science of light.

Sincerely yours,

A. C. Gilbert

GILBERT LIGHT EXPERIMENTS

FUN WITH BRIGHT SUNLIGHT

Experiment No. 1. To obtain more than one million miles of sunshine. Go outside with your watch in your hand and stand in the sunlight (Fig. 1) for just six seconds. In that short six seconds you will have received more than 1,000,000 miles of sunlight. Light travels at the enormous velocity of 186,000 miles per second, and therefore in six seconds you receive on your body $186{,}000 \times 6 = 1{,}116{,}000$ miles of sunlight.

Fig. 1. You receive 1,000,000 miles of sunshine

Experiment No. 2. To receive over two thousand million million light waves. Hold your hand in a beam of sunlight (Fig. 2) for six seconds and then withdraw it.

Fig. 2. You receive 2,000,000,000,000 light waves

You will show soon that white light is a mixture of lights of all colors. Now the red light waves in the sunlight fall on your hand at the rate of 390 million million per second and in six seconds $390 \times 6 = 2340$ million million fell on your hand. Your hand received many more than this because waves of all colors fell on it, and of violet light alone it received twice the above number.

Repeat this experiment with a candle flame, or oil lamp, or electric light. In each case your hand receives more than two thousand million million light waves in the six seconds.

Fig. 3. Shutter to darken room

TO MAKE YOUR DARK ROOM

Boys, you are going to make many experiments with a beam of sunlight let into a darkened room, so prepare for them now thoroughly, as follows:

Select in your home a room with only one window, facing the south or east or west. Now cover this window so that **no light** can enter the room except through a small slit. The best way to do this is to make a solid wooden shutter, with tar paper on one side, to cover the whole window and make a slit in it three inches wide and two inches high. If the window is too large for this, make a wooden shutter (Fig. 3) for the lower part and cover the upper part with black cloth, black paper, a quilt, a heavy blanket (Fig. 4), or anything that will shut out all light. Make the slit in the wooden part because you will want to change the size and

Fig. 4. Shutter in window with other side showing and with cardboard tacked over slit

shape of the slit. To do this you will make slits of the right kind in black tar paper or cardboard and then tack these over the slit in the wooden shutter. Make the shutter so that you can take it down and put it up quickly, because you will want to experiment many times and your mother will, probably, not want to leave the window permanently darkened.

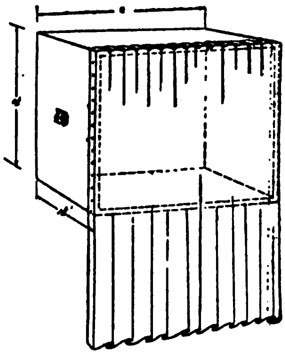


Fig. 5. Your dark box

TO MAKE A DARK BOX

If you cannot make a dark room, you can make a dark box (Fig. 5), as follows: Take a packing box $1\frac{1}{2}' \times 1\frac{1}{2}' \times 2'$ or larger, bore a hole $2\frac{1}{2}$ inches in diameter in the center of one end, cover the open top with a piece of dark light-proof cloth, $4' \times 3'$, tacked to the ends and one side. Plait this along the side to leave room for your head and shoulders. Make the box light-proof, turn it on its side with sunlight entering the slit, and you are ready to make your experiments.

It improves the box to paint it black on the inside. When you need a slit, cut it in cardboard and tack the cardboard over the $2\frac{1}{2}$-inch hole. This hole will just take your large ring lens holder when you experiment with lenses.

A dark room is more fun than a dark box, and the directions in this book assume that you have made one. You will find, however, that you can make most of the dark-room experiments in the dark box. It is an excellent idea to have both.

Experiment No. 3. To show that you cannot see a beam of light unless it falls on some object or directly on your eyes. Darken the room on a day when the sun is shining in the window. Leave the room for five minutes to let the dust settle and then return. Do you find that you cannot see the beam **between**

Fig. 6. Dust makes the beam visible

the slit and a screen or the wall or floor?

Make a dust near the beam by shaking your coat or a carpet. Do you now appear to see the beam (Fig. 6)? You do, because the dust particles reflect light to your eyes.

On a clear night you cannot see the beam from the headlight of a locomotive; but when there is mist, rain, or snow, you appear to see it because particles of these reflect light to your eyes. In either case you can see any object the beam falls on because it re-

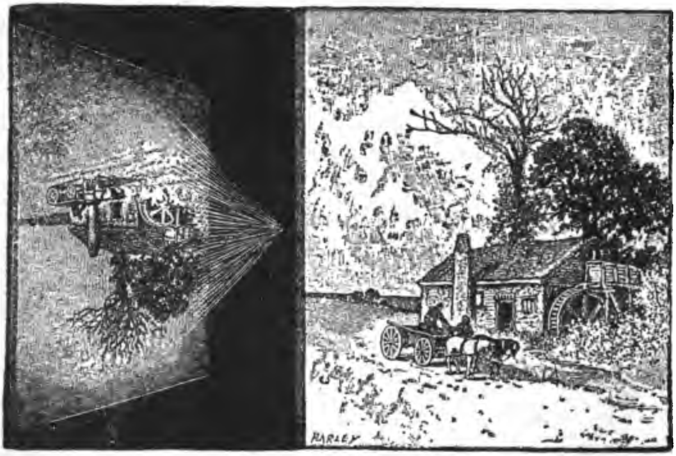


Fig. 7. A beautiful inverted picture
From Appleton's School Physics, published by the American Book Co.

flects light to your eyes. You can also see the light if it falls directly on your eyes.

Experiment No. 4. To show that light travels in a straight line. Make a dust near the beam. Does the light travel in a straight line from the slit to the wall or floor or paper screen?

Fig. 8. You see a beautiful picture in natural colors

Experiment No. 5. To get a picture of all out-of-doors. Punch a nail hole in a piece of black paper or cardboard, tack the paper or cardboard over the slit in your darkened room, and hold a sheet of tissue paper about one foot from the hole. Do you find on the paper a picture (Figs. 7 and 8) of the whole view out-of-doors opposite the hole? Is the picture **inverted** and in **natural colors?** Can you see men, horses, and automobiles moving?

This is a fascinating experiment, and it shows best when the sun is shining on the landscape and not on the window.

The picture is **inverted** because light travels in **straight lines.** The sunlight which falls on any part of a cloud, for example, is reflected in all directions in straight lines, and a very small part of this light passes through the hole to the **bottom** of the tissue paper. Also the sunlight which falls on any object on the ground is reflected in all directions in straight lines, and a very small part of this passes through the hole to the **top** of the tissue paper, and so on. That is, the picture is inverted because light travels in a **straight** line from each object through the hole to the paper.

The picture is in **natural colors** because each object reflects **light of its own color** and absorbs the remainder. That is, the blue sky, green grass, and red bricks reflect blue, green, and red light respectively, and so on.

Move the paper farther from the hole. Is the picture larger but dimmer? It is larger because the rays from different parts of the view **cross** at the hole and **diverge** afterward. It is dimmer because only a certain amount of light passes through the hole, and it covers a larger area the farther the paper is from the hole. Punch a second nail hole two inches from the first. Do you now get two pictures? Do they blur where they overlap? Punch many holes. Do you get as many pictures, but do they blur more and more?

Open the slit to its full size. Do you find that there is no picture at all, but just white light? There is no picture because light from all parts of the view falls on all parts of the picture and the combination of all colors produces white light.

Make a hole the size of a lead pencil in a new piece of black paper and tack the paper over the slit. Do you get a brighter picture, but is it more indistinct than with the nail hole? Remove the tissue paper. Is there a picture on the opposite wall? This will show only if the sun is shining brightly on the view, and if your room is completely dark except for the light which passes through the hole.

Experiment No. 6. To get a picture of the sun. Allow a beam of sunlight to pass through a nail hole into your darkened room, catch it on a piece of paper and move the paper back and forth. Is the image round (Fig. 9) and is it larger the farther the paper is from the hole?

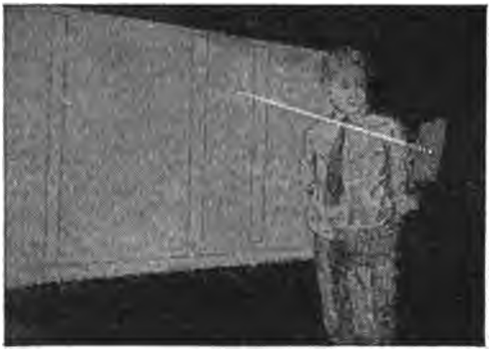


Fig. 9. You see one image of the sun

The image is round because the sun is round. It increases in size because the light rays from the sun travel in straight lines and

cross at the hole. The upper side of the sun sends out light in all directions in straight lines; a very small part of this passes through the hole (H, Fig. 11) and makes an image of itself at the bottom of the picture; similarly light from the lower side of the sun makes an image of itself at the top of the picture, and so on. Reflect the light to the farthest part of the room by means of a mirror. Is the image larger the farther it is from the hole? Punch two holes. Do you get two images (Fig. 10)? Punch many holes. Do you get many images, but do they overlap?

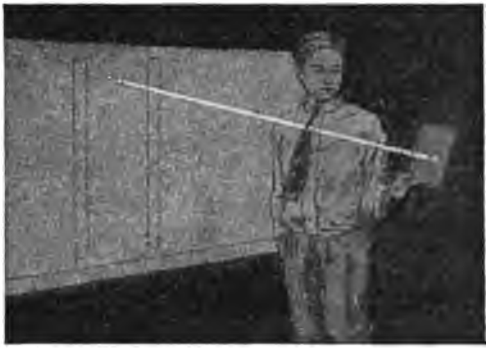


Fig. 10. You see two images of the sun

Open the slit entirely. Do you get only a bright spot in the shape of the slit? This spot is made up of many, many round images, and you will notice that the edges and corners are somewhat blurred and not sharp.

Take a new piece of black paper, make a triangular hole one-quarter inch on a side, tack it over the slit and get an image of the sun at one inch from the hole, then at greater and greater distances. Is the image at first triangular and does it become more and more blurred at the sides and corners until finally it is round? The image is made up of many small, round images of the sun, and when these are large

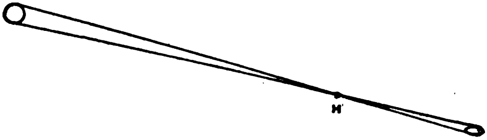


Fig. 11. The rays cross at the nail hole

compared to the size of the hole they overlap and produce a round image.

Repeat with a square hole one-quarter inch on each side. Are the results similar?

You have probably noticed that sunlight produces round images of the sun when it passes through any small opening; for example, in a shutter or blind, between the leaves of trees, and so on. The explanation is that given above.

Experiment No. 7. To make a pinhole camera. Make a nail hole in the middle of the bottom of a cardboard box, cover the open top with a piece of tissue paper (Fig. 12), hold the hole toward a brightly lighted landscape, cover your head and the tissue paper with a black cloth or blanket to shut out all the light (Fig. 13), and look at the tissue paper. Do you see a beautiful image of the landscape **inverted** and in **natural colors?**

Fig. 12. The open side of the box is covered with tissue paper

This is a beautiful experiment and it is explained as above.

You can actually make pictures through a pinhole, as follows: Remove the lens from a camera, cover the opening with heavy tin foil and pierce the foil with a pin. Now to take the pic-

Fig. 13. You see a beautiful picture on the paper

ture, cover the pinhole, arrange the plate or film in position, uncover the pinhole for a short time, cover it, and develop your negative as usual.

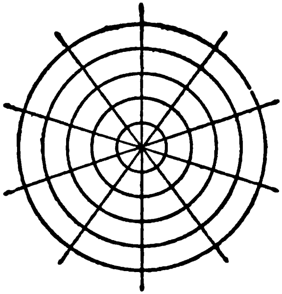


Fig. 14. Spherical waves and straight rays

SOMETHING ABOUT LIGHT

Now, boys, before we go any further let us get some clear ideas about light.

Light is that which produces on the eyes the sensation of sight.

Medium. A medium is anything through which light travels; for example, air, water, glass, and the ether.

Ether. The ether is supposed to be a very thin and elastic medium which fills all space, not only the space between the planets, but also the space between the smallest particles (molecules) of solids, liquids, and gases.

How Light is Produced. Light is produced by the vibration of very hot particles of matter.

For many reasons, scientists believe that the smallest particles of all substances are vibrating, that is, moving back and forth in all directions, all the time, and that the hotter they are the faster they vibrate. Now in the flame of a candle, oil lamp, or gas jet there are particles of unburned carbon which are very hot and are, therefore, vibrating rapidly. These vibrating particles set the ether in the flame in vibration, and these vibrations spread out

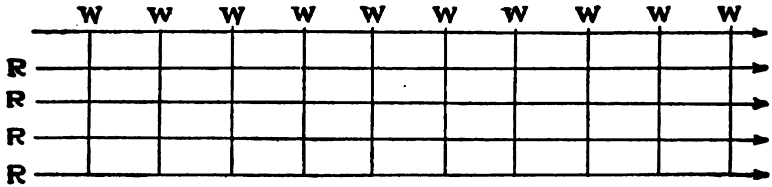


Fig. 15. A beam of light. W = parallel waves. R = parallel rays

in all directions in the form of spherical waves in the ether. These ether waves are light waves or heat waves.

Similarly the light of an incandescent electric arc light or of the sun is produced by rapidly vibrating hot particles of matter.

Note. Heat waves are longer than light waves and do not produce the sensation of sight, but they are similar to light waves in all other respects.

Waves and Rays. If the dot in the center of Fig. 14 is a rapidly vibrating particle, the circles about it will give the position of

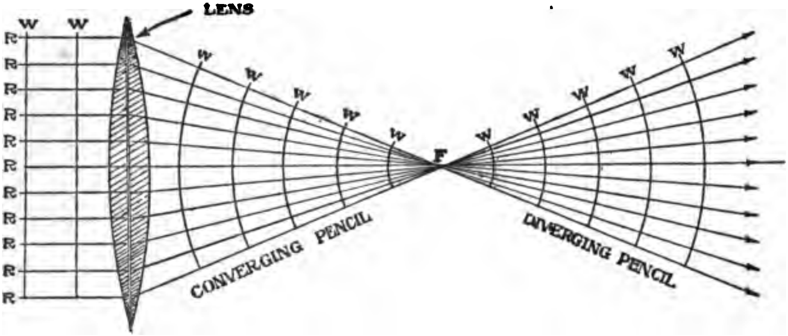


Fig. 16. The lens produces a converging pencil and a diverging pencil
W = waves. R = rays

its light **waves** after equal intervals of time, but the light waves are spherical instead of circular. The straight arrows drawn from the center represent light **rays.** They give the path along which the light is traveling in all directions from the center. The light waves are real and produce the sensation of sight; the rays are not real, they are imaginary, straight lines which give the direction of the light and they are always at right angles to the waves.

Parallel Waves and Rays. The waves from the dot are larger the farther they are from the center, and when they are one hundred yards or a mile from the center they are very large indeed. If your eye receives light from any such distant point the small part of the waves which enter it are nearly parallel straight lines,

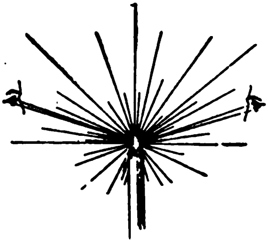


Fig. 17. The candle sends rays in all directions
From Appleton's School Physics, published by the American Book Co.

and since the rays are always at right angles to the waves they are also nearly parallel. This is particularly true if the distant point is the sun, at a distance of ninety million miles. **Parallel waves** and **rays** then are those from a distant source.

Beam. Pencil. A **beam** (Fig. 15) is a group of parallel waves and rays. A **pencil** (Fig. 16) is a group of waves and rays which converge at a point or diverge from it. The eyes (Fig. 17) are receiving diverging pencils of light from the candle which is sending out light in all directions.

Luminous and Non-luminous Bodies. Luminous bodies are those which give out light, such as the sun, electric light, gas jet, oil lamp, candle, and match. Non-luminous bodies are those which do not give out light, and which can be seen only by means of light from luminous bodies.

Transparent, Translucent, and Opaque Bodies. Bodies which you can see through are called **transparent**; such as air, water, and glass. Bodies which let light through, but which you cannot see through, are called **translucent**; as paper, ground glass, and cotton cloth. Bodies which do not transmit light are called **opaque**; for example, wood, brick, and metal.

Fig. 18. Unburned carbon in a flame

No substance is entirely opaque; for example, even metals let through some light when they are in very thin sheets.

Straight Lines. Light always travels in straight lines from its source until it falls on some object or until it

Fig. 19. Circular waves on water

passes into another medium. It then changes direction but again travels in straight lines from the object or in the new medium.

Experiment No. 8. Carbon particles in a flame. Hold a saucer in a candle flame (Fig. 18). Is it blackened? The blackening is caused by the unburned carbon particles.

Experiment No. 9. Water waves. Look along the surface of water in a pan and dip a pencil in and out. Do you observe circular waves (Fig. 19)? Throw a stone into a still pond or lake. Do you see circular waves? These illustrate light waves, but the light waves are spherical.

FUN AT NIGHT

Experiment No. 10. How you see things. Boys, when you have attended movie shows where they have animated cartoons you have perhaps seen a dotted line move from the eye of the hero (or villain) to the object he is looking at. You might think from this that you see an object by means of light which goes from your eye to it. This is not the case, however, as you will now prove.

Fig. 20. You see the book by reflected light

Take an unlighted candle into an absolutely dark room and

Fig. 21. Light travels in a straight line to your eye

look around. Can you see anything? You cannot because all the objects in the room are non - luminous, including yourself and your eyes. This proves that you do not see things by means of light which goes from your eye to the thing you are looking at. Now light the candle. The flame is a luminous body and you see it by means of light which goes from it to your eye.

Can you now see the non-luminous bodies? You can because light travels from the candle flame to these objects and from them to your eye (Fig. 20).

You have proved here that you see any object by means of light which travels from it to your eye and not the reverse.

Experiment No. 11. To show that light, when not reflected or refracted, travels in a straight line from the object to your eye.

Fig. 22. Light travels in a straight line

Note. The thing you are looking at directly or indirectly is called the object.

Close one eye, look at the flame of a candle, and then move a book slowly between the flame and your eye (Fig. 21). Do you find that you cannot see the flame when the book has crossed the straight line between the flame and your eye? This proves that the

Fig. 23. You see an inverted image of the candle

light from the flame travels in a straight line to your eye.

Close one eye and look at any part of some other object, then again move the book across the straight line from the part to your eye. Do you find again that you cannot see the part when the book has crossed the straight line between the part and your eye?

Cut three pieces of cardboard about 5"×3", punch a small hole in each at the same height, stand them upright on the table, place a candle flame in front of an end hole, and look at the flame through the three holes (Fig. 22). Shift the cardboards one at a time. Do you find that you can see the flame only when the holes are in a straight line?

Note. You will show later that light is bent out of the straight line when it is reflected from a mirror and when it is refracted in passing from air to water, air to glass, and so on.

You have shown here that light, which is not reflected or refracted, travels in a straight line from the object to your eye.

Experiment No. 12. Picture of a candle flame. Punch a nail hole in card **C** and arrange as shown in Fig. 23. Do you see an inverted image of the flame and is it larger the farther

Fig. 24. Flash-light telegraphing

	INTERNATIONAL CODE	AMERICAN MORSE CODE
A	· —	· —
B	— · · ·	— · · ·
C	— · — ·	· · ·
D	— · ·	— · ·
E	·	·
F	· · — ·	· — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	· — — —	— · — ·
K	— · —	— · —
L	· — · ·	⸺
M	— —	— —
N	— ·	— ·
O	— — —	· ·
P	· — — ·	· · · · ·
Q	— — · —	· · — ·
R	· — ·	· · ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	— · · —	· — · ·
Y	— · — —	· · · ·
Z	— — · ·	· · · ·
&		· · · ·
1	· — — — —	· — — ·
2	· · — — —	· · — · ·
3	· · · — —	· · · — ·
4	· · · · —	· · · · —
5	· · · · ·	— — —
6	— · · · ·	· · · · · ·
7	— — · · ·	— — · ·
8	— — — · ·	— · · · ·
9	— — — — ·	— · · —
10	— — — — —	⸺

Fig. 25. Light telegraphing

D is from C? Make the hole larger. Is the image brighter but more blurred? Can you explain these facts as in Experiments 5 and 6 and as illustrated in Figs. 11 and 23?

Experiment No. 13. Flash-light telegraphing. You can telegraph to your friends at night by means of flash-light signals (Fig. 24) and the Morse code. Use a short flash for a dot and a long flash for a dash. For the Morse code see page 19.

Experiment No. 14. Telegraphing with a candle or lamp. Arrange the apparatus as shown in Fig. 25 and have a friend make a similar arrangement in a window facing you. You can then telegraph by means of the Morse code. Uncover the light for a short time to produce a dot and for a longer time for a dash.

INTENSITY OF LIGHT

If you hold a book 1 foot from a lighted candle, it receives a certain amount of light; if you hold it 2 feet from the candle, it receives only one-fourth as much light; if you hold it 3 feet from the candle, it receives only one-ninth as much light, and so on. That is, **the intensity of the light on any object varies inversely as the square of the distance between the object and the source of light.**

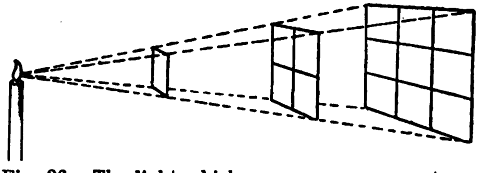


Fig. 26. The light which covers one square at one foot covers four and nine at two and three feet, and is then only one-fourth and one-ninth as intense

In Fig. 26 the light

which would cover 1 square at 1 foot would cover 4 and 9 equal squares at 2 and 3 feet and would therefore be one-fourth and one-ninth as intense.

Experiment No. 15. To prove the law of intensity. Screen **A**, Fig. 27, has a hole just 1 inch square and screen **B** a square 3 inches on each side, divided into 9

Fig. 27. The light is one-ninth as strong on B as on A when B is 3 feet from the candle

square inches. Place **A** 1 foot from the candle and **B** 2 feet. Does the light which passes through 1 square inch in **A** cover 4 square inches on **B**? Is it, therefore, only one-fourth as intense on **B** as it is on **A**? Place **B** 3 feet from the candle. Does the light now cover 9 square inches? Is it, therefore, only one-ninth as intense? This proves that the intensity of light varies inversely as the square of the distance.

Experiment No. 16. A greased spot. Rub a small piece of butter on the center of a piece of paper and melt it.

Look at the spot by reflected light (Fig. 28). Is the spot dark? Look at it by transmitted light

Fig. 28. The spot is dark by reflected light

Fig. 29. The spot is bright by transmitted light

(Fig. 29). Is it bright? It is darker than the paper in the first case and brighter in the second, because more light goes through the greased spot than through the paper.

Experiment No. 17. Four candles against one. Put four candles 2 feet from the greased-spot screen and one candle 1 foot on the other side (Fig. 30). Trim the wicks until the flames are of equal size.

Is the greased spot as bright as the paper? It is, because the light which goes through from one side is exactly equal to that which goes through from the other, that is, the one candle throws as much light on the screen as do the four candles. This is explained by the law of intensity mentioned above. Each of the four candles is 2 feet from the screen and therefore throws just one-fourth as much light on the screen as one candle does at 1 foot.

Fig. 30. One candle at one foot is equal to four at two feet

Experiment No. 18. Candle power of a lamp. The candle power of a lamp is the

number of times greater or less its light is than that given by a standard candle.

Put the greased-spot screen just 1 foot from a candle (Fig. 31) and move the lamp until the greased spot is as bright as the paper. Measure the distance from the lamp to the screen. If this is 2 feet, the lamp is 4-candle power; if 3 feet, 9-candle power; 4 feet, 16-candle power; and so on. This follows from the law of intensity of light.

Fig. 31. Finding the candle power of the lamp

The instruments used to measure the candle power of lamps are called photometers, and the one you have here illustrated is named after its inventor, Bunsen's photometer (Fig. 32). **A** is the greased-spot screen, **B** the standard candle, and **C** the light tested.

Experiment No. 19. Four against one. Place a candle 1 foot from a screen and four equal candles just 2 feet from the screen, and place an object in front of the screen as in Fig. 33. Are the shadows of equal darkness?

If the candle flames are all of the same size, the shadows are equally dark because each light illuminates the shadow produced by the other and because the candle at 1 foot sends as much light to the screen as the four candles do at 2 feet from the screen. This is explained by the law of intensity.

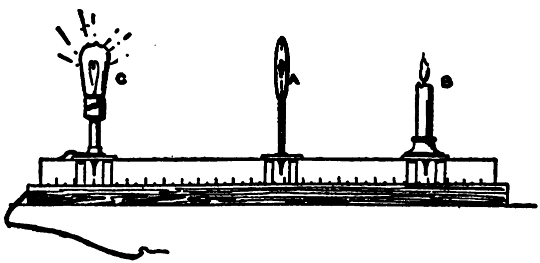


Fig. 32. Bunsen's photometer

Experiment No. 20. Shadow photometer. Put a

Fig. 33. One candle equal to four
From Millikan and Gale's First Course in Physics, Ginn & Co.

candle 1 foot from a screen (see Fig. 34, illustrating shadow photometer), stand a pencil in front of the screen, and move the lamp back and forth until the two shadows are equally intense. Measure the distance from the screen to the lamp. If this is 2, 3, 4, or 4½ feet, the candle power of the lamp is 4, 9, 16, or 20¼, and so on.

Each light illuminates the shadow cast by the other and therefore when the shadows are equal the lights are equal, and the candle power is calculated as above from the law of intensity of light. This illustrates the shadow photometer.

SHADOWS

Experiment No. 21. Enlarging shadow. Move a pencil from the screen toward the candle (Fig. 35). Does the shadow increase in size? It does, because light goes in all directions in straight lines from the flame, and the pencil intercepts more light the nearer it is to the flame.

Fig. 34. Illustrating the shadow photometer

SHADOW ENTERTAINMENTS

Boys, you can have the greatest kind of fun by giving shadow shows to your friends, and the

Fig. 35. Shadows

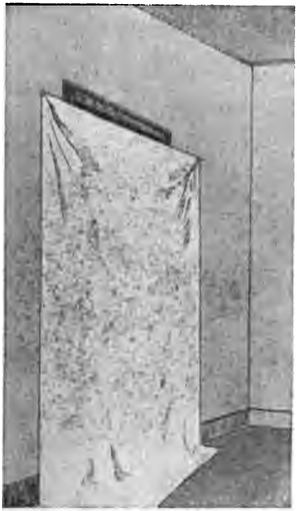


Fig. 36. A sheet over a doorway

preparation you need is very slight. Hang a sheet over a folding doorway as shown in Fig. 36.

Now opposite the door put a strong lamp on a stool, chair, or table, according to the show (Fig. 37). The audience is in darkness on the other side of the screen.

Show 1. The Dentist. Dentist seated, bell rings, boy comes in with bandaged head, dentist seats him and examines tooth, boy howls, dentist takes very, very large pliers, and pulls out a very large cardboard tooth (Fig. 38). The tooth, of course, was stuck in boy's coat collar

Fig. 37. Showing lamp on a chair

Fig. 38. The dentist

at one side. Use much pantomime all through the show.

Show 2. The Doctor. Doctor seated with very large plug hat and very long beard, bell rings, boy enters rubbing stomach and groaning. Doctor seats him, takes pulse, examines tongue, listens to heart, all with much pantomime, takes large coal tongs, shoves them down boy's throat (apparently, of course), and

Fig. 39. The doctor

pulls up a long snake (Fig. 39). More pantomime. Boy not yet well, doctor again shoves tongs down his throat and pulls up an alligator, and so on. Much pantomime of boy feeling fine.

The snake and alligator are cut out of stiff paper or cardboard and are handed up by a third boy as shown in Fig. 40.

Fig. 40. How it is done

Show 3. A Surgical Case.

Scene 1. A boy is seated at a table with large plate of potatoes. He swallows them whole, then swallows knife, fork, spoon, saltcellar, and so on. Much pantomime of enjoying a good meal.

Scene 2. Doctor seated at table, boy rushes in rubbing stomach, doctor lays him on table, takes large knife, jabs it into boy's stomach (Fig. 41), boy raises head to object, doctor hits him on head with hatchet (Fig. 42) and proceeds to cut him open, throws back coat to imitate opening stomach, and takes out all the potatoes, knife, fork, spoon, and so on. Doctor sews boy up, hits him on head with hatchet, boy comes to, pantomime of feeling fine, shakes hands with doctor and thanks him.

Fig. 41. A surgical case

Fig. 42. Quieting the patient

The knife and axe are cut out of cardboard, the plug hat is a tube of stiff paper on an ordinary hat, the whiskers are another tube of paper. The boy swallowing potatoes really hands them to another boy hidden beside the chair.

Show 4. A Boxing Match.

Fig. 43. A boxing match

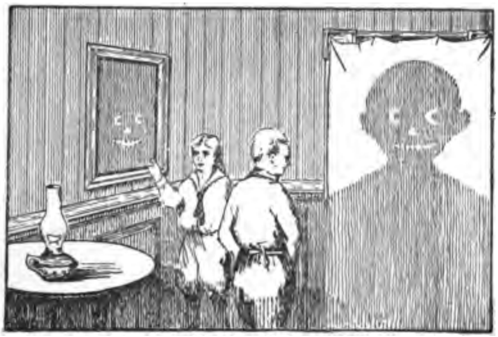


Fig. 44. Living shadows

Put one boy near the screen and another nearer the light. The first is natural size, the second is enormous (Fig. 43). If they now pretend to fight it is very, very funny from the audience. In one of the fights, have the lamp on the stool, let the little fellow beat the big fellow, and if the big fellow finally runs away and steps over the lamp to the chair it looks as though he had jumped into the ceiling. Little fellow then struts around as winner.

Show. 5. Living Shadows. Cover a mirror with two pieces of paper, out of each of which you have cut identical eyes, nose, and mouth with teeth, as shown in Fig. 44. Paste the under paper against the mirror, but paste the outer paper only at the top. Arrange the light and boy as shown and sway the outer paper back and forth. Do you see goggling eyes and snapping mouth?

Now have the boy, whose shadow is shown, make a speech with proper gestures, while you sway the paper. The effect will be extremely amusing to the spectators.

Show 6. Living Shadow Dialogue. Arrange two mirrors as above and place one on each side of the screen. Have the two shadows carry on a dialogue while two other boys sway the papers.

You will have plenty of fun inventing shows of your own, and with a few beards, mustaches, and false noses made of paper or of other material you can have very, very funny times.

REFLECTION OF LIGHT

The Law of Reflection: Angle of reflection equals angle of incidence. If a beam of sunlight is allowed to fall on a mirror and the beam before and after reflection is made visible by dust in the air, it is found that the beams make equal angles with a ruler held perpendicular to the mirror, and that they are in the same plane. The beam **I**, Fig. 45, which strikes the mirror is called the **incident** beam, and the beam **R** which is reflected is called the **reflected** beam. The angle **i** which the incident beam makes with the perpendicular **PN** is called the **angle of incidence,** and the angle r which the reflected beam makes with the perpendicular is called the **angle of reflection.** This experiment illustrates the **Law of Reflection,** which is: **The angle of reflection equals the angle of incidence and the reflected and incident beams are in the same plane.**

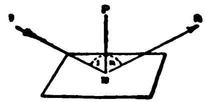


Fig. 45. The angle of reflection R is equal to the angle of incidence I

FUN WITH SUNLIGHT

Experiment No. 22. To prove the law of reflection. Allow a small beam of sunlight to pass through the slit of your shutter and fall on a mirror placed on the floor or table of your darkened room. Make sufficient dust to show the sunlight. Is the sunlight reflected and does it make a bright spot on the ceiling or opposite wall?

Fig. 46. The beams make equal angles with your ruler

Now hold a ruler

Fig. 47. The beams are in the same plane

perpendicular to the mirror opposite the spot where the light strikes the mirror (Fig. 46). Do you find that the angle between the reflected beam and the ruler is equal to the angle between the incident beam and the ruler?

Hold a sheet of cardboard edge-wise to the incident and reflected beams in such a position that the incident beam is split in two (Fig. 47). Is the reflected beam also split in two? That is, are the reflected and incident beams in the same plane?

You have here proved the law of reflection.

Experiment No. 23. Irregular reflection. Let the beam fall on a piece of white unglazed paper (Fig. 48). Is there no reflected beam; is the light reflected in all directions and does it make everything around it brighter? The light is reflected in all directions because the surface is rough (see Fig. 49).

Fig. 48. There is no reflected beam from rough paper

Fig. 49. Irregular reflection
From the Ontario High School Physics, by permission of the publishers

You see all non-luminous objects by means of light which they reflect irregularly.

Experiment No. 24. Twice the angle. Hold the mirror perpendicular to the beam. Is the beam reflected back to the slit? Now turn the mirror to an angle of 45° to the beam. Is the reflected beam turned through an angle of 90°? That is, is the reflected beam turned through **twice the angle** the mirror turns? Try other angles. The reflected beam turns through twice the angle because the angles of incidence and reflection are equal and each is equal to the angle through which the mirror turns, therefore, together they are equal to twice this angle.

Fig. 50. Heliographing

FUN BY DAY WITH ONE MIRROR

Experiment No. 25. The heliograph. Reflect sunlight from your window (Fig. 50) to a distant building, and have your friend reflect sunlight from near this building to your window.

Now send a message to your friend by the Morse code. Uncover your mirror for a short time for a dot and for a longer time for a dash. He reads the message on the wall of the building. He replies and you read the message on the inside wall of your room. This is the principle of the heliograph used for military signaling.

Experiment No. 26. Height of any point on a building. Drive one end of a straight stick into the ground and make the stick exactly vertical. Place the mirror B, Fig. 51, beside it flat on the ground and adjust until the stick and its image are in a straight line; the mirror is then exactly horizontal.

Fig. 51. You find the height of the window by reflection

Now if you want to find the height of the topmost window, for example, stand back until you can just see the top of the window, then measure: your distance **BC** from the mirror; the distance **BE** from the mirror to the building; and your height **CA** from sole to eye.

The triangle **ABC** which you make with the mirror is similar to the triangle **DBE** which the top of the window makes (Fig. 51), that is, they have equal angles, therefore,

$$\frac{\mathbf{DE}}{\mathbf{EB}} = \frac{\mathbf{AC}}{\mathbf{CB}}$$

Examples. If you are 12 feet from the mirror, your height to your eye is 5 feet, and the mirror is 120 feet from the building at the ground level, then:

$$\frac{\text{Height of window}}{120} = \frac{5}{12}$$

$$\text{Height of window} = \frac{5 \times 120}{12} = 50 \text{ feet}$$

FUN BY DAY OR NIGHT WITH ONE MIRROR

Experiment No. 27. An object and its image. Look at yourself in a vertical mirror and move back and forth. Does your image always appear to be as far behind the mirror as you are in front?

Arrange the window glass vertically, place a candle in front and another behind (Fig. 52), and make the rear candle coincide with the image of the front candle. Measure the distance from each candle to the mirror. Are they exactly equal?

Fig. 52. The candles are at equal distances from your mirror

Draw a line on a piece of paper and call it the mirror line (Fig. 53). Draw three lines across it, and perpendicular to it, at 2-inch intervals. Place the window glass vertically on the mirror line, place the front candle on each perpendicular in turn. Is its image candle always at the same distance from the mirror?

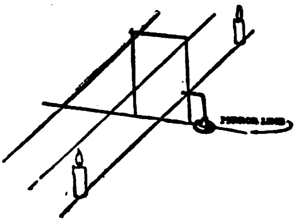


Fig. 53. The candles are on the same perpendicular

You have proved here that an image is always the same distance behind the mirror that the object is in front; and that it is on a perpendicular drawn from the object across the mirror line.

Experiment No. 28. Slanting object. Place a pencil in front of the vertical window glass (Fig. 54), and slanting toward the glass. Make a second pencil of equal length coincide with the image. Does the image also slant toward the mirror? It does, because each part of

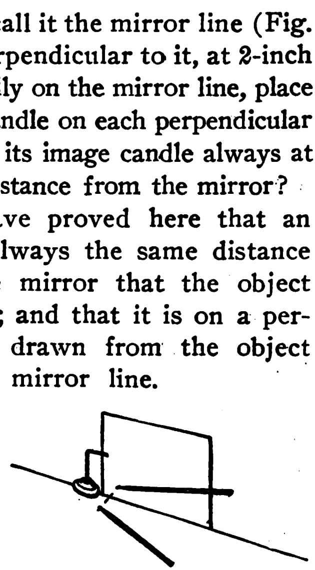


Fig. 54. Both pencils slant toward your mirror

Fig. 55. You copy a drawing easily

the image is as far behind as the corresponding part of the object is in front, and both are on a line perpendicular to the mirror line.

Experiment No. 29. To copy a drawing. Arrange drawing, vertical window glass, book, paper, and light, as shown in Fig. 55. Do you find it easy to copy the drawing? Why is the drawing reversed?

WHY THE IMAGE IS AS FAR BEHIND THE MIRROR AS THE OBJECT IS IN FRONT

We will explain this first by means of rays and then by means of waves, but you must remember that what you actually receive in your eyes is light waves and not rays. The rays are only imaginary lines which show the direction the waves are moving.

In Fig. 56 the eye sees image **B**, but the light, of course, goes from **A** to the mirror and is reflected to the eye. The angles **r** and **i** are equal by the law of reflection; also, since **CD** and **AB** are parallel, angle **A** is equal to **i** and angle **B** is equal to **r**. Therefore angles **A** and **B** are equal; also the angles at **F** are equal, since they are right angles. The triangles **CFA** and **CFB** then have two angles equal and a side **CF** in common, therefore they are equal

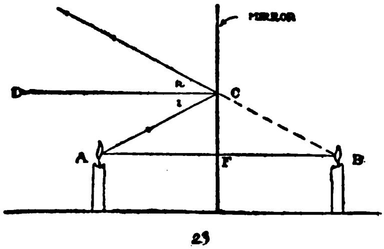


Fig. 56. The ray appears to come from B

and **FB** is equal to **AF**. This shows that the image is as far behind the mirror as the object is in front because by the law of reflection r is equal to i.

We will now explain by means of light waves why the image and objects are at equal distances from the mirror, as follows:

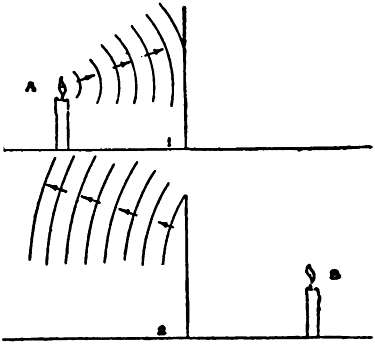


Fig. 57. The waves appear to come from B

The waves of light from the candle **A** strike the mirror as in **1**, Fig. 57, and are reflected as in **2**. The curvature of the waves is exactly reversed by reflection. The eye estimates the distance of an object partly by the curvature of the waves which enter it, and the image appears at **B** as far behind the mirror as the object at **A** is in front, because the reflected waves which enter the eye have exactly the curvature they would have if the mirror were absent and the object were at **B**.

We see, then, that the image of **A** is at an equal distance **B** because the waves from **A** are reversed by the mirror but unaltered in any other way.

Fig. 58. You see circular waves reflected

Experiment No. 30. To illustrate reflected waves. Fill with water a cake tin with flat sides (Fig. 58), place it near a good light, dip a pencil in, two inches from one side. Is the reflected wave

Fig. 59. Your right hand is an image of your left and *vice versa*

curved in the opposite direction to the original wave? Is it larger and is it the size it would be if it came from a point at an equal distance outside the pan? This is what happens when a light wave strikes a mirror.

Experiment No. 31. Why your image is reversed. Hold your two hands in front of you (Fig. 59). Is one a reversed image of the other?

Hold your left hand in front of a mirror (Fig. 60). Does it appear to be your right hand? It does, because each point of the image is the same distance behind the mirror that the corresponding part of the left hand is in front.

Experiment No. 32. Reversed words. Print such words as STAR, STUN, and TOP on paper and look at their images (Fig. 61). Are they reversed? Why?

Experiment No. 33. Reading a blotting paper. Write a sentence in ink, blot it on fresh blotting paper. Try to read it. It is hard. Read it in the mirror (Fig. 62). Is it easy? Why?

Fig. 60. Your left hand appears to be the image of the right

Experiment No. 34. To see behind you. Hold the mirror in

front of you as in Fig. 63. Can you see behind you with ease? Why?

Experiment No. 35. To see around a corner. Hold a mirror as in Fig. 64. Can you see around a corner with ease? Why?

Fig. 61. You see a different word

EXPERIMENTAL MAGIC

Experiment No. 36. A candle burning in a glass of water. Place candle in front of window glass and glass of water behind it, as in Fig. 65. Does the candle appear to burn in the water?

Experiment No. 37. Phantom candle in boy's head. Arrange apparatus as in Fig. 66. Does the candle appear to burn in the boy's head?

Experiment No. 38. Phantom flame. Arrange the apparatus as in Fig. 67 and hold your hand behind in the image of the flame. Can you do this quite safely?

Experiment No. 39. To make magical transformations. Arrange the apparatus as in Figs. 68 and 69. Place the lighted candle in position **1** and adjust block **A** until it coincides with the image of block **B.**

Fig. 62. You read a blotting paper easily

Now to prepare a transformation, fold a sheet of paper once

Fig. 63. You see behind your back

over at the middle, and on the top half make a drawing of a man. Make it with a lead pencil and bear down so as to crease the lower half. Now draw on the lower half inside the creases the skeleton of a man. Tear the halves apart, attach the man to **B** and the skeleton to **A**, and adjust until the man seems to turn into a skeleton when you move the candle from position **1** to position **2**.

Now darken the room and ask a friend to look into the glass, as in Fig. 69, while you move the candle from **1** to **2**. He will be much mystified.

Use photos of the same size, one of a boy and the other of a girl, and make the transformation. Make many other transformations.

You may have seen similar magical transformations at the theater or in side shows.

Fig. 64. You see around a corner

Experiment No. 40. A magic box. Make out of stiff cardboard a square box 24 inches

Fig. 65. You see the candle burning in water

long and 3¾ inches wide and high. Cut the box into two equal parts at an angle of 45° (see 1, Fig. 70), turn the halves as in 2, cut a hole in one half, its center being 2 inches from the end. Cut two trapdoors and attach to each a loop of cord for opening it. Now insert the window glass at the division, see 3.

Now to have fun with your friends, hide the box behind a large sheet of paper or cardboard and have your friends look through a hole in the paper or cardboard into the hole in the box.

Have the box in a good light and have different objects beneath the trapdoors. If you now open one trapdoor, the object beneath is seen by your friends. If now you close the first door and open the second, the object will appear to be transformed into the other object.

Fig. 66. You see the candle burning in the boy's head

Use an empty glass and a glass half full of milk and you can make the tumbler empty and fill at will.

You can make many other very funny transformations.

Fig. 67. The candle appears to burn in your hand

FUN AT NIGHT

Hypnotism

Boys, you can put on imitation hypnotism shows which will mystify and amuse your friends, as follows:

Get a piece of window glass 2 feet by 3 feet, or larger. Put it in a box (Figs. 71 and 72) at an angle of 45° to the length of the box and exactly vertical. Paint the inside of the box black. The box is open toward the audience, also at the opposite end, **B1, B2, B3,** and at the side, **A1, A2, A3.** A strong light **1** is placed at the side and throws light on a person sitting opposite **A1, A2,** or **A3,** but not on the glass. A weaker light **2** is placed so that it will throw light on a person seated opposite **B1, B2,** or **B3,** but not on the glass. When light **1** is up, a boy seated opposite **A1, A2,** or **A3** will be seen by the audience by reflected light as seated at **B1, B2,** or **B3.** When light **2** is up, a boy seated at **B1, B2,** or **B3** will be seen at **B1, B2,** or **B3** by direct light. The direct image is brighter than the reflected, and to cut it down tack two or three layers of green or black mosquito

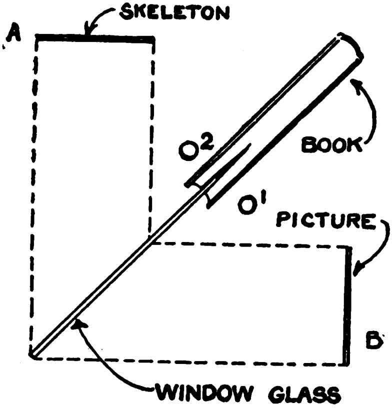


Fig. 68. Transformations

Fig. 69. How you arrange glass, book, pictures, and candles

netting over the B opening. Use black backgrounds behind A and B; this is important.

You should always try out your apparatus just before you use it. Look at the window glass from the audience side, have both lamps lighted, and the boy **A** will appear to be seated beside boy **B.** If **A** appears too low, tilt the glass toward **A**; if he appears too high, tilt the glass toward **B.** If the glass is exactly vertical, **A** and **B** will be at exactly the same height.

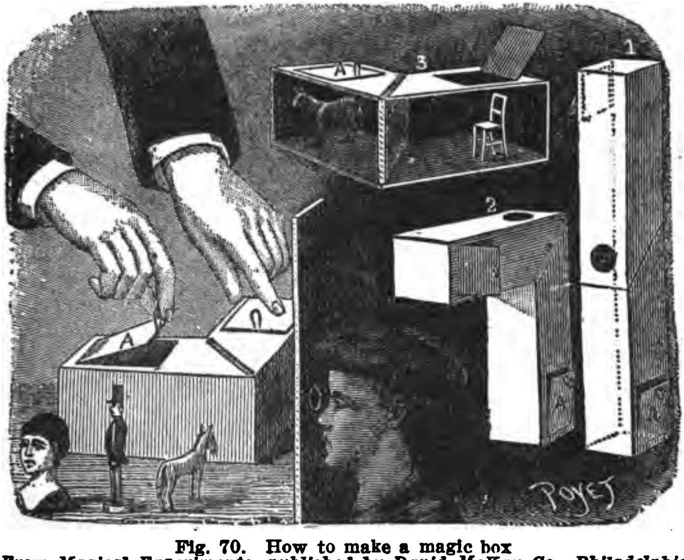


Fig. 70. How to make a magic box
From Magical Experiments, published by David McKay Co., Philadelphia

Now have an assistant turn down lamp 1 and **A** will disappear, turn up lamp 1 and **A** appears again. Also turn light 2 down and up and **B** disappears and reappears.

These shows need five boys. One is the hypnotist, who stands out in front and gives the patter talk to the audience. He can wear a dress suit, mustache, tall hat, and so on, if he desires. Two boys are needed as the hypnotism subjects, who occupy chairs **A** and **B**, as required. The remaining two boys are needed to operate the lamps.

You will invent all kinds of shows for yourselves and make up your own patter talk, but we suggest a few that will make plenty of fun.

Show 1. To hypnotize a boy at a distance of ten feet and to make him disappear and reappear.

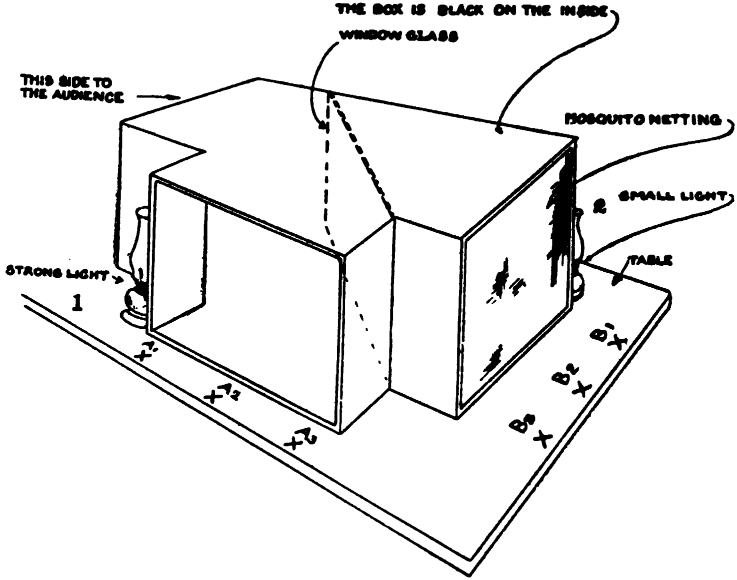


Fig. 71. Your hypnotism box

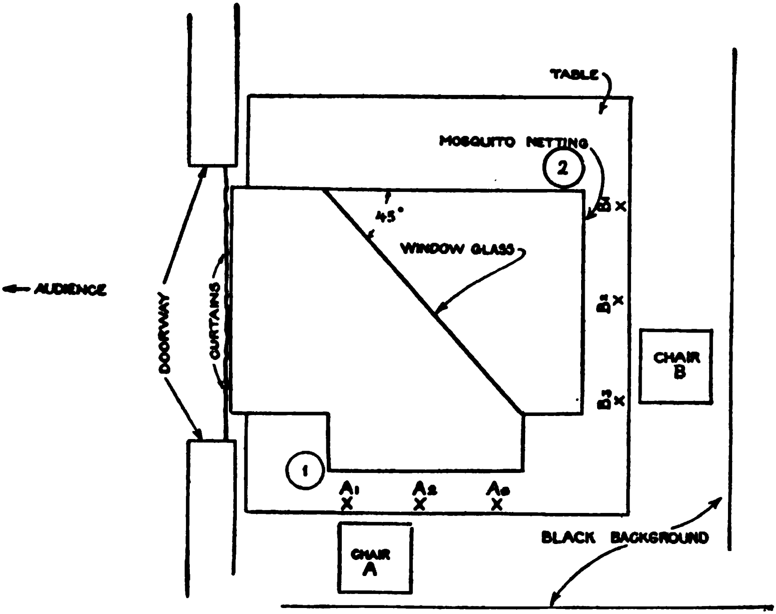


Fig. 72. Plan of hypnotism apparatus

Patter. "Ladies and Gentlemen, I have much pleasure in announcing that I will to-night give you an exhibition of hypnotic power more wonderful than anything you have yet seen. It may surprise those of you who know me to learn that I have been studying hypnotism for years, and it will surprise you still more to learn that I have discovered a secret source of hypnotic power of immensely greater strength than any such power discovered up to this time. Former hypnotists have hypnotized their subjects at a distance of one or two feet; but I dare not do this because my power is so great that it might injure the subject. I will do all my work at a distance of ten feet, which I have found to be a perfectly safe distance. I do not care to explain my power any more than to say that I have in the cabinet powerful bodies

which bathe my subjects in electro-magnetic forces and help me in my work." (**Note.** This is perfectly true because lamps give out light and light is electro-magnetic in nature; of course, do not tell the audience this.) "Now without further talk I will give an exhibition of my hypnotic power by hypnotizing Charles at a distance of ten feet." (Raises curtain.)

Note. Charles is seated at center position, **B2** (see Fig. 72). Light **2** is turned up and **1** is turned down. Chair at side is in position **A2.**

Hypnotist: "Charles, attention!" (Makes passes with hands slowly and says, "Sleep! Sleep! Sleep!" slowly. Charles shivers, gets rigid, and slowly closes eyes.)

Hypnotist: "Now, Ladies and Gentlemen, former hypnotists have made their subjects do such simple things as rise in the air, remain floating in the air, and so on. On another occasion I will show you some of these simple things, but I will now give you a much more wonderful example of hypnotic power. I will make Charles dissolve into thin air and disappear entirely."

Hypnotist (to Charles): "Charles, avaunt! Avaunt! Avaunt!" (slowly with passes). (Lamp **2** is slowly turned down and at the same time **1** is slowly turned up. Charles gradually fades into nothing, but the chair is apparently left.)

Hypnotist: "Ladies and Gentlemen, Charles has now joined the spirit world; but for the sake of his family and friends, I will call him back. I must do this quickly or he may get beyond my power, great as this is." (Looking at ceiling) "Charles, appear!" (Looking at glass) "Appear! Appear!" (slowly). (Light **1** is slowly turned down and **2** slowly turned up and Charles slowly appears.)

Hypnotist snaps his fingers. Charles wakes up and smiles. Hypnotist drops curtain, bows to the audience, and goes behind the curtain to help arrange for the next show.

Show 2. To hypnotize a boy, turn him into another boy, and

then turn him back again. (Charles is seated at position **B2**, lamp **2** is up; Henry is seated at position **A2**, lamp **1** is turned down.)

Hypnotist: "Ladies and Gentlemen, I will now give you an even greater example of my hypnotic power. Other hypnotists make their subjects believe that they are some one else, but I will actually turn my subject into another being and right before your eyes. Now watch carefully and please do not talk, because I have to concentrate my will to make this transformation, and if my attention is diverted my subject might be left half changed, which would be very serious indeed."

(Raises curtain, speaks to Charles) "Charles, attention!" (Makes short passes and says) "Sleep! Sleep! Sleep!" (slowly).

(To audience) "Now, Ladies and Gentlemen, if you will keep perfectly quiet I will change Charles into another boy."

(To Charles) "Charles, change! Change! Change!" (slowly).

(Light **2** is slowly turned down and **1** slowly turned up. Charles turns into Henry slowly. Henry is also asleep. Hypnotist snaps fingers — Henry wakes up and smiles.)

Hypnotist: "Now, Ladies and Gentlemen, it would never do to leave these boys mixed up in this way because their mothers would never know which is which, not to mention their best girls, so I will turn them back again. Now quiet, please. Henry, attention!" (He mesmerizes Henry with passes and saying, "Sleep! Sleep! Sleep!" Henry stiffens and closes eyes. He then says, "Change! Change! Change!" and Henry slowly changes to Charles as light **2** is turned up and **1** down.)

Hypnotist wakes up Charles, drops curtain, bows, and retires behind curtain again.

Show 3. Transmigration of souls.

Hypnotist: "Ladies and Gentlemen, my next exhibition of my hypnotic power will deal with the transmigration of souls. You have all heard of this strange Hindu theory, namely, that

our souls have passed down the ages and have migrated from one animal or man to another. Now I have traced Charles's soul history, and it is very interesting. I have not the time to show you all the forms it has taken, but I will show you the animals his soul inhabited one thousand, two thousand, and three thousand years ago."

(Raises curtain, mesmerizes Charles as before, then says) "O ancient soul form! Come! Come! Come!" (Makes passes and bows three times toward Charles.)

(Charles slowly changes to a dog. Charles is at **B2**, dog is on a box at **A2**. At first light **2** is up and light **1** is down. The dog appears as **2** is lowered and **1** is turned up.)

Hypnotist: "Charles is a very nice boy, and you see that one thousand years ago his soul inhabited the body of a very nice dog. I will now show you the body his soul inhabited two thousand years ago."

(Turns toward dog, makes passes, bows three times, and says) "O more ancient soul form! Come! Come! Come!"

(While hypnotist is talking Charles has left his seat and a cat on a box is put in his place. The dog now changes to a cat as light **2** is turned up and light **1** down.)

Hypnotist: "You see that Charles's soul two thousand years ago occupied the body of a very beautiful cat. I will now show you the body his soul occupied three thousand years ago."

(Makes passes toward cat, bows three times, and says) "O most ancient soul form! Come! Come! Come!"

(The dog has been replaced by a bird in a cage and the cat changes to a bird as light **1** is turned up and light **2** down.)

Hypnotist: "Ladies and Gentlemen, Charles's soul occupied the body of a beautiful bird three thousand years ago. I will now turn the bird back to Charles. Otherwise the cat might eat Charles up, and I am afraid Charles's mother would not forgive the cat or me."

(Makes passes at bird and says) "Charles, appear! Appear! Appear!"

(Charles has taken his place again at B2 and appears as light 2 is turned up and 1 down.)

Hypnotist snaps fingers and awakens Charles, drops curtain, bows, and retires.

Show 4. The transmutation of metals.

Hypnotist: "Ladies and Gentlemen, those of you who know the history of the sciences know that all through the ages and down to the present time, scientists have been trying to change the base metals into the noble metals,—lead into silver, iron into gold, and so on. All such attempts have previously failed, but I wish to announce modestly to-night that I have succeeded, with the help of my marvelous hypnotic power. I will now prove this to you by changing iron into other metals."

(Raises curtain showing a flatiron—or any iron object—on a box. He makes passes at the iron and says) "O spirit of iron, depart! O spirit of silver, come! Come! Come!" (The iron slowly changes to a silver cake basket, or any object of silver.) (The iron object is on a box at B2, the silver object is on an exactly similar box at A2. At first light 2 is up, the iron disappears and the silver appears as 2 is turned down and 1 up.)

Put a gold object in place of the iron, and change silver to gold, and so on.

Show 5. To hatch an egg. Have an egg on one box and a chicken on the other, and slowly change the egg to a chicken. It is even funnier if you have a full-grown hen. Pretend that your power is not strong enough, great as it is, to change the hen back to the egg.

Show 6. Astral bodies.

Hypnotist: "Ladies and Gentlemen, I will next give you an exhibition of occultism, and I will show you the results of a marvelous discovery I have made. I have discovered a liquid

with remarkable powers. If a person drinks this liquid he is immediately changed to his astral body. This body appears to the eye to be the same as ever, but it is composed of bound ether only and has no substance. I may say that this has nothing whatever to do with hypnotism; the effects are produced entirely by the liquid."

(Raises curtain, disclosing Charles and Henry apparently seated side by side with a glass of liquid — water or milk — in front of each. Charles is at **A1** and Henry is at **B3.** Both lights are up.)

Hypnotist: "You now see Charles and Henry. Boys! Drink some of the powerful liquid." (The boys do so.) "Now, Ladies and Gentlemen, the boys appear to you the same as before, but they are not.

"Charles! Put your hand gently through Henry." (Charles does so.) "Henry! Do you feel anything?" (Henry shakes his head to indicate, no.)

"Henry! Put your hand gently through Charles." (Henry does so.) "Charles! Do you feel anything?" (Charles moves lips.) "You say you don't feel anything, but you wish he would wash his hands."

Hypnotist: "You see, Ladies and Gentlemen, their bodies have no substance. They are simply astral bodies made up of bound ether. I will prove this further.

"Charles! Slice Henry gently with the butcher's knife." (Charles does so.) "Henry! Does it hurt?" (Henry moves lips.) "What! You like it?" (Henry nods yes and moves lips.) "You like it because it makes you feel like a sliced orange?" (Henry nods, yes.)

"Henry! Chop Charles gently with a hatchet." (Henry does so.) "Charles! Does it hurt you?" (Charles shakes head and moves lips.) "It doesn't hurt you and you like it because it makes you feel like minced meat?" (Charles nods, yes.)

Hypnotist: "Now, Ladies and Gentlemen, I will show you

another evidence of the marvelous power of this liquid. I will have Charles pour some of the liquid on an apple and thereby turn it into an astral apple. He will then give it to Henry to eat.

"Charles! Change the apple and give it to Henry." (Charles changes apple by pouring a little liquid on it out of the glass, but instead of giving it to Henry he starts eating it himself. Henry objects and apparently knocks the apple out of Charles's hand. They sit in their chairs and each punches many times to the right. Their fists go right through each other.)

Hypnotist drops curtain and apologizes solemnly to the audience, saying that he is sorry the astral bodies got beyond his control. He bows and retires.

Show 7. Power of the will over supernatural beings.

Hypnotist: "Ladies and Gentlemen, I will now conclude the entertainment of the evening by giving an exhibition of the power of the human will over supernatural beings. Charles has just had a terrifying experience and I am going to help him out."

(Raises curtain and shows Charles seated at **B1.** Charles is frightened and keeps looking over first one shoulder then the other.)

Hypnotist: "Now, Charles, calm yourself and tell us exactly what happened." (Charles moves lips.) "You say you just saw a ghost up the dark road near Fred's house." (Charles nods and moves lips.) "Did you run?" (Charles nods, yes.) "Were you afraid?" (Charles shakes head, no.) "Why did you run then?" (Charles moves lips.) "Oh, you just wanted to see whether you could beat him running?" (Charles nods, yes.) "Did you beat him?" (Charles nods, yes.) "Where did you leave the ghost?" (Charles moves lips and waves hand toward door.) "You left it at the front door?" (Charles nods, yes.) "Can it get in?" (Charles shakes head and moves lips.) "Oh, you locked the door. Well, it doesn't matter because you aren't afraid of ghosts, anyway." (Ghost gradually appears beside Charles. Henry, covered with

sheet, is seated at **A3** and appears at **B3** as light **1** is turned up.)

(Charles is much startled, strikes at ghost with fists, then with knife, drops knife with a clatter, takes up hatchet and strikes at ghost; Charles is much agitated. Ghost is calm all through this; it just looks at Charles, but now it moves over into Charles. (Henry moves from chair **A3** to **A1**.) Charles claws at his own neck, trying to tear out ghost.)

Hypnotist now calls out, "Charles, calm yourself! I will help you. You cannot get rid of the ghost because it is your own ghost, but now just sit steady and I will pin the ghost to the chair by my will power and when I say, 'Come!' get up quietly and come out here in front."

(Hypnotist looks intently at ghost, makes passes, and says quietly) "Come!" (Charles comes out in front.)

Hypnotist: "Now, Charles, look at your own ghost. Do you want to get rid of him entirely?"

Charles: "Yes."

Hypnotist: "All right. Now watch quietly and I will send him away." (Looking at ghost and pointing finger at him) "O ghost of Charles, disappear and never come back! Disappear! Disappear!" (slowly). (Ghost disappears as light **1** is turned down.)

Hypnotist: "Ladies and Gentlemen, this concludes our entertainment for this evening. Thanking you all for your kind attention, I bid you good-night." (Bows and retires.)

ELEVATIONS

The illusion show (Fig. 73) has a sheet of plate glass **GG** at an angle of 45°. You can put on a similar show by turning your box on its side. You can make a boy appear to rise in air and stay there. The boy is lying on his back on a rug in place of **T** and has his legs folded as though he were sitting with crossed legs. The hypnotist then makes proper passes and

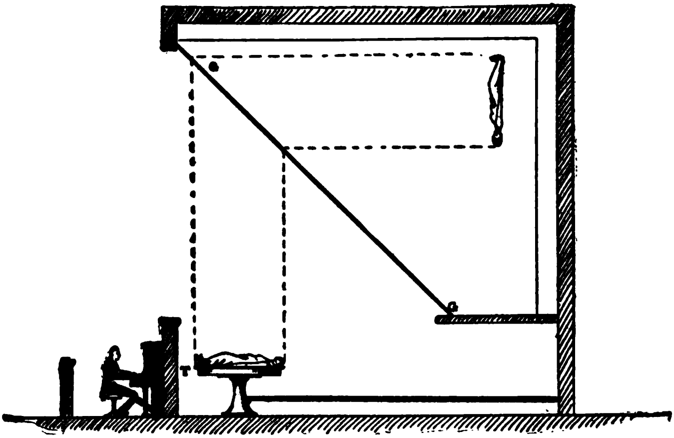


Fig. 73. Illusion show
Permission of Hurst and Company, publishers of children's books and toys

commands him to rise. Two concealed boys at T pull the rug and the boy appears to rise. He can then be turned upside down and back again. You can repeat with the boy lying down.

FUN BY DAY OR NIGHT WITH TWO MIRRORS

Experiment No. 41. Magic money. Stand the two mirrors vertically on the table sidewise to a good light and place a coin between them. Look over each mirror in turn into the other (Fig. 74). Have you multiplied your money wonderfully?

Fig. 74. You see many coins

Experiment No. 42. Magic lights. Repeat the above in the dark with a lighted candle between the mirrors

Fig. 75. You see many lights

(Fig. 75). Do you find many, many lights?

Experiment No. 43. Magic army. Put a number of lead soldiers on a narrow strip of paper and draw them between the vertical mirrors (Fig. 76). Do you see an immense army marching in perfect order?

Experiment No. 44. Magic dancers. Cut out of paper or cardboard a small figure of a man dancing. Attach him to a string and make him dance between the mirrors in a good light (Fig. 77). Do you find a multitude of dancers who keep time perfectly?

Experiment No. 45. Magic silver or copper mine. Separate the mirrors by two blocks, place them one above the other and face to face (Fig. 78); place a silver or copper coin on the lower mirror. Do you find yourself looking down into a very deep hole with many silver or copper coins in it?

Fig. 76. You see an army

Why you see Many Images in Parallel Mirrors. You

Fig. 77. You see many dancers

see many images between two parallel mirrors because the image formed in one mirror is an object in the other, and so on.

In Fig. 79, two mirrors, **A** and **B**, 4 inches apart are facing each other and a candle between them is 1 inch from **B** and 3 inches from **A**.

In **B** the image **B1** is formed 1 inch behind **B** and in **A** the image **A1** is formed 3 inches behind **A**.

Now image **A1** is 7 inches in front of **B** and it forms an image **B2** 7 inches behind **B**; similarly image **B1** is 5 inches in front of **A** and forms an image **A2** 5 inches behind **A**. Again, **A2** is 9 inches in front of **B** and forms an image **B3** 9 inches behind **B**, and so on.

Fig. 78. You look into a very deep hole containing much money

You see many images because the light which enters your eyes has been reflected one or more times.

If you are looking at **B1**, the light which enters your eye appears to come from **B1**, but it comes from the candle and is reflected from **B**.

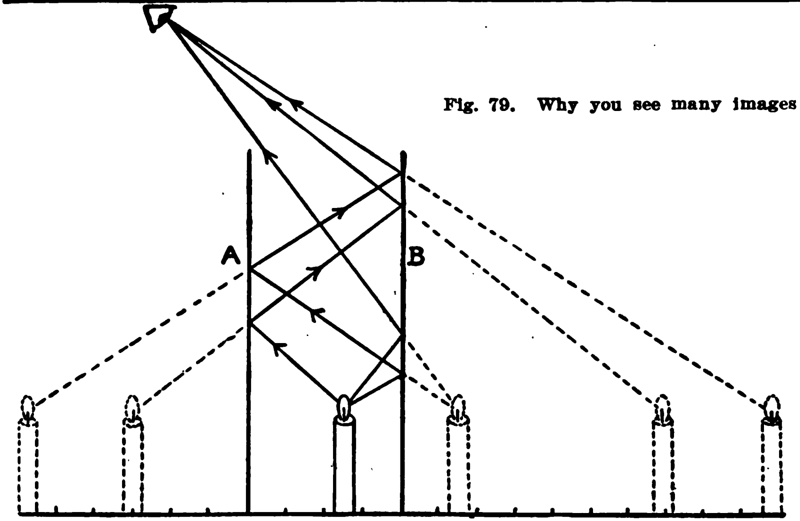


Fig. 79. Why you see many images

If you are looking at **B2**, the light appears to come from **B2**, but **B2** is an image of **A1**, and the light goes from the candle and is reflected twice before it enters your eye.

Image **B3** is an image of **A2**, which in turn is an image of **B1**, and you see **B3** by means of light which has been three times reflected. Similarly you would see **B4**, **B10**, and **B50** by means of light reflected 4, 10, and 50 times.

Fig. 80. You see over the book

It is good practice to locate the images in parallel mirrors and to trace the paths of the light.

Why the Images become dim. The images become dimmer the farther they are

Fig. 81. You see over your head

away: first, because some light is absorbed by the mirrors at each reflection; and, second, because the light has traveled a long distance in being reflected back and forth between the mirrors.

Experiment No.46. The trench periscope. To illustrate how the periscope works, look over the top of a tall book as shown in Fig. 80. Place one mirror against the book at an angle of 45° and hold the second mirror above the book at the same angle. Can you see over the top easily without being seen yourself? Turn the upper mirror until it looks backward (Fig. 81). Can you see back over your head, but is everything upside down? Turn the upper mirror until it looks sidewise (Fig. 82). Can you see things, but are they turned on their sides?

THE "WHY" OF THE PERISCOPE

Fig. 82. You see things at the side

Now let us see why the image is right side up in some cases and not in others.

The mirrors in the regular periscope are parallel to each other, and you can locate the image in each mirror in turn as you

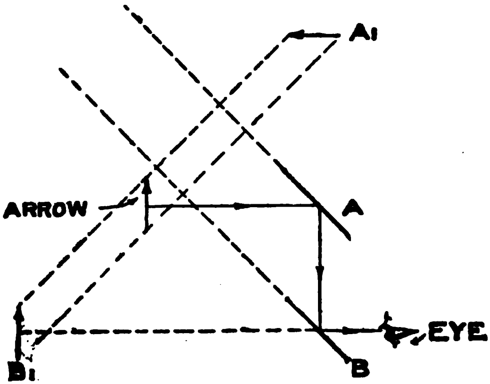


Fig. 83. The "why" of the periscope

did in the case of parallel mirrors.

Let the arrow, Fig. 83, represent the object; its image in **A** is **A1** and the top and bottom of **A1** are as far behind the mirror extended as the top and bottom of the arrow are in front.

Now let us suppose mirror **B** to be extended as shown by the dotted line, then **B1** is the image of **A1** in this extended mirror and the top and bottom of **B1** are as far behind **B** as the top and bottom of **A1** are in front of **B**, and therefore **B1** is right side up.

In the second case, the mirrors are at right angles (Fig. 84). **A1** is the image of the arrow in **A** extended and **B1** is the image of **A1** in **B** extended; **A1** is on its side and **B1** is inverted for the reasons given above.

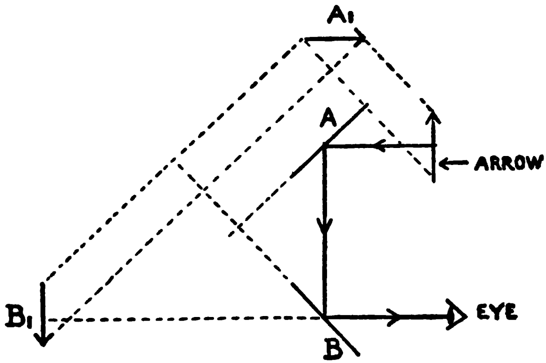


Fig. 84. Why things are upside down

In the third case, the image is on its side in the upper mirror, and since the lower mirror is parallel to this image, the image in the lower mirror is still on its side.

Experiment No. 47. To make a

trench periscope. Get a block of wood 4" × 4" × 6", measure down 1 inch from each end and draw a line across diagonally. This line will be at 45° to the length of the block. Cut the block through on this diagonal line, see right side Fig. 85.

Fig. 85. The completed periscope and the block used in it

Now attach a mirror to each diagonal face by means of tacks. Cut a piece of stiff cardboard 17 inches wide and as long as you wish to make the periscope. Tack this to the block, overlapping 1 inch on one side. Paste the overlapping parts together. Cut a hole 3" × 3" opposite the upper mirror and a hole 2" × 2" opposite the lower mirror, and your periscope is finished.

You can use this periscope in your trench battles; also you can use it on a train to see forward without putting your head out of the window. In this case, however, you should fasten the window glass over one of the holes to keep cinders out of your eyes.

Fig. 86. You see four candles

FUN WITH MIRRORS AT DIFFERENT ANGLES

Experiment No. 48. Mirrors at different angles. Stand the mirrors vertically and at right angles on the table (Fig. 86) and place a lighted candle

between them. Do you see four candles, the real candle and three images?

Make the angle 60°. Do you see six candles, the original candle and five images?

Make the angle 45°. Do you see eight candles?

Make the angle 30°. Do you see twelve candles?

There are 360° in a complete circle, and the number of candles you see in each case is 360 divided by the angle between the mirrors. For example, when the angle is 90°, you see $\frac{360}{90}$ or 4 candles; and when the angle is 60°, you see $\frac{360}{60}$ or 6 candles; and so on.

Experiment No. 49. A one-boy crowd. Stand the mirrors at 90° and put your face close to the mirrors. Are there four of you, yourself and thrce images?

Repeat with the mirrors at the angles mentioned above. Do you find yourself a crowd all in a circle?

Experiment No. 50. Arrows. Stand the mirrors at 90° on a piece of white paper and draw an arrow pointing at one of the mirrors. Do some of the arrows point in one direction and some in the opposite direction? Keep one mirror in such a position that the arrow points directly at it and move the other mirror until the angle is 60°. Do the six arrows point toward each other in pairs?

Repeat with the mirror at the other angles mentioned above.

Experiment No. 51. An infinite number of candles. Light a candle and stand the mirrors close to it and gradually make them parallel. Do you see very, very many candles?

When the mirrors are parallel the angle between them is 0°, and $\frac{360}{0}$ is infinity, so you should see an infinite number of

images. You cannot, because some light is lost at each reflection and finally all is lost.

Experiment No. 52. To locate the images in mirrors at an angle. Draw two lines 4 inches long at right angles to represent two mirrors at right angles (Fig. 87) and extend them backward by dotted lines to represent the extended mirrors. Place a dot 1 inch from **A** and 2 inches from **B**, then image **A1** will be 1 inch behind **A** and image **B1** 2 inches behind **B**. The third image **A2B2** is an image of both **A1** and **B1**; it is 1 inch behind **A** extended and 2 inches behind **B** extended.

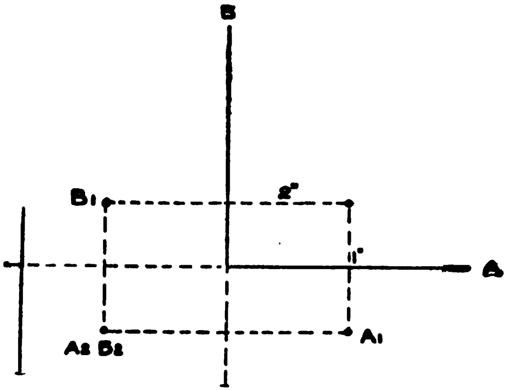


Fig. 87. The "why" of mirrors at right angles

It is harder to locate the images when the angle is 60° or smaller, but it will help you to know that the images are always all on the circumference of a circle of which the angle of the mirrors is the center.

Practice locating the images in mirrors at 60°.

Experiment No. 53. The kaleidoscope. The kaleidoscope (Fig. 88) consists of two mirrors at an angle of 30° in a tube which has an eye opening at one end and at the other a chamber containing pieces of col-

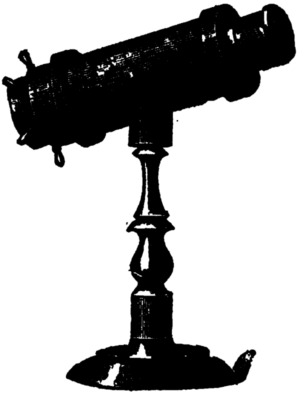


Fig. 88. The kaleidoscope

Fig. 89. You see many twelve-sided figures

ored glass. When you look through the tube and revolve it, the colored pieces of glass make beautiful twelve-sided figures by multiple reflection.

Illustrate the working of the kaleidoscope as follows: Draw two lines at an angle of 30° on a piece of white paper. Stand the mirrors on a block above these lines with the angle toward a good light (Fig. 89). Now put pieces of colored paper and other small objects on a strip of paper and draw the paper under the angle, while you look down between the mirrors with your eye near the angle. Do you see a series of twelve-sided figures?

ILLUSIONS

The Sphinx. This illusion shows an Egyptian head without a body (Fig. 90). The hypnotist shows the audience an empty box with a glass front. He closes and locks the door over the front, places the box exactly on the center of the table, unlocks it, opens the door, and, behold, there is an

Fig. 90. The Egyptian head

Egyptian head in the box. The hypnotist stands near the audience and addresses the head. "O ancient Sphinx, awake! Awake! Awake!" The sphinx slowly opens its eyes and stares straight ahead. The hypnotist then addresses questions to it and it answers in very deep and very dead tones, and so on. Finally the hypnotist locks the box, brings it forward to the audience, opens it, and there is nothing in it but a handful of ashes.

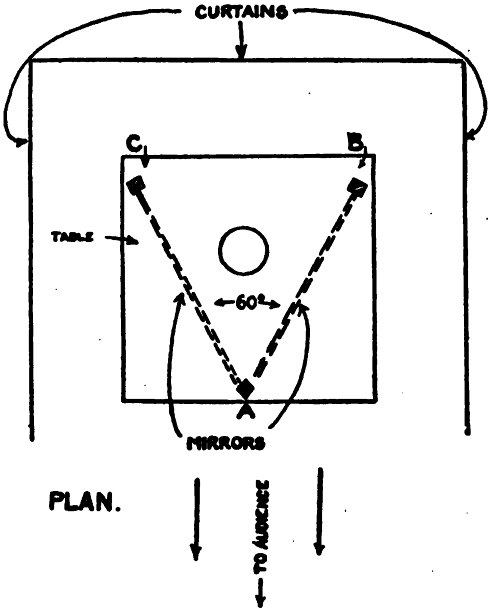


Fig. 91. Plan of the table

The mechanism of this illusion is illustrated in Fig. 91. The table is on three legs, **A, B, C,** with mirrors at 60° between **A, C,** and **A, B.** The curtains at the back and sides are exactly alike, and to the audience the images of the side curtains appear to be the back curtain, and the space under the table appears quite empty.

Cabinet of Proteus. The performer puts his assistant into the cabinet (Fig. 92), closes the doors a moment, makes passes, open doors (Fig. 93), and the assistant is gone. Closes doors again, makes passes, opens doors, and out comes an entirely different man. Closes doors again, makes passes, opens doors, and out comes a lady. Closes doors again, makes passes,

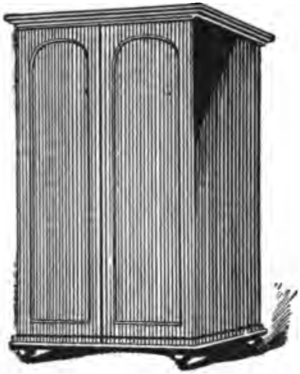


Fig. 92. Cabinet closed
From Hoffman's Modern Magic

opens doors, and out comes assistant.

To the audience, the cabinet appears entirely empty except for a post, **C**, with a strong light at the top. There are, however, two hinged mirrors, **ab** and **ab**, Fig. 94, at an angle of 60° and the post covers the angle. The sides and back are exactly alike and the images of the sides in the mirrors appear to the audience to be the back. The man, lady, and assistant, of course, hide behind the mirrors. Members of the audience stand behind and beside the cabinet all through the performance. The assistant swings the mirrors against the sides before he comes out the last time, and then members of the audience are asked to examine the cabinet, when, of course, they find nothing.

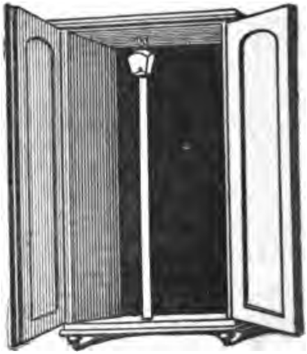


Fig. 93. Cabinet open
From Hoffman's Modern Magic

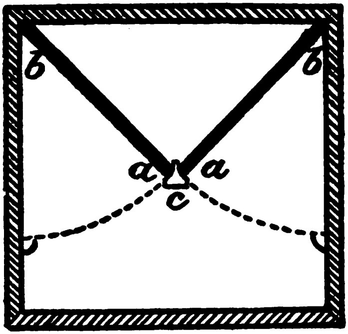


Fig. 94. Plan of cabinet
From Hoffman's Modern Magic

Illusion Show. Pharaoh's thumb. Make a table out of cardboard (Fig. 95) and stand it on three legs, each of which is exactly 5¼ inches from the other two, and place your two mirrors between **A** and **B** and **A** and **C**. Surround it by screens on three sides, making the sides and

back exactly alike and exactly the same distance from the table.

Now have an assistant put his arm through a hole in the back curtain and put his blackened thumb up through a hole in the table top, and you are ready to begin the act.

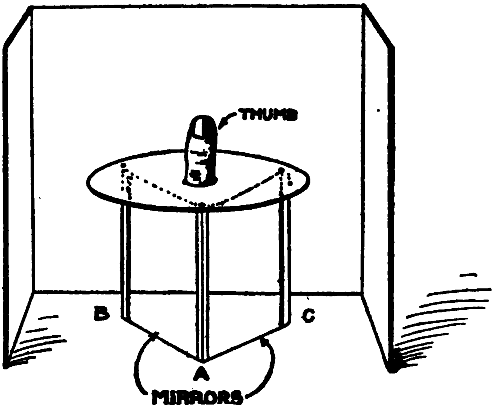


Fig. 95. Pharaoh's thumb

Explain to the audience that you have succeeded in bringing to life the thumb of an ancient pharaoh by your hypnotic power. Explain that the thumb was lost in battle, fell on the sands of the desert and dried but did not decompose. This pharaoh was a great hypnotist, which makes it easier for you to bring his thumb back to life. Explain also that the thumb will answer any question about the future. If the thumb moves forward it is, yes; if it doesn't move at all it is, no.

Now open the curtains, address the thumb, "O Thumb of an ancient Pharaoh, awake! Awake! Awake!" (slowly and with passes). The thumb does not move. You now ask, "O ancient and sacred Thumb, will Charles get his wish?" (Thumb slowly nods, yes.) "O ancient and sacred Thumb, will Henry get through his examinations?" (Thumb does not move. No.) And so on.

Vaudeville Act. The acrobat. You can put on a short but very funny act with a mirror (Fig. 96) placed at an angle to the audience.

Fig. 96. You become a marvelous acrobat
From Magical Experiments, published by David McKay Co., Philadelphia

FUN WITH THE CURVED MIRROR

Experiment No. 54. Converging sunlight. Open the slit in your darkened room to its full size and allow the sunlight to fall on the concave (curved-in) side of your curved mirror. Make a dust. Is the sunlight converged to a point and does it diverge beyond this point (Fig. 97)? This point is the focus of the mirror.

Experiment No. 55. Diverging sunlight. Turn the convex (curved-out) side of the mirror to the sunlight (Fig. 98). Is the sunlight reflected and diverged or spread?

Fig. 97. You see a brilliant focus in dusty air

Experiment No. 56. Picture of the sun. Remove the shutter, stand the mirror on the table in the sunlight, and focus the sunlight on a strip of paper ½ inch wide (Fig. 99). Is the picture of the sun round and very bright?

Experiment No. 57. The focus is very hot. Focus the sunlight on your hand with the concave mirror (Fig. 100). Is it hot? It is, because all the heat of the sunlight is concentrated at the focus.

Experiment No. 58. To light a match with sunlight. Place a match in front of a narrow strip of paper (Fig. 101) and focus the sunlight on the head. Does the match light?

Experiment No. 59. A magic cannon. Stick a needle into the under side of a cork and stick a match on the other end of the needle (Fig. 102), with a small piece of paper at one side of the head. Insert the stopper in an empty bottle, focus the sunlight on the match head through the glass sides (Fig. 103). Does the match light and are the cork, needle, and match driven out with a satisfactory pop?

Fig. 98. You see the light spread

Fig. 99. You see a brilliant picture of the sun

The lighted match heats the air and the expanding air drives out the cork.

Experiment No. 60. Focal length of concave mirror. Focus the sunlight on a narrow piece of paper and measure the distance between the back of the mirror and the paper. This is the focal length of the mirror. Do you find it to be about two inches?

Experiment No. 61. Focal length of convex mirror. Make two pencil dots just 2 inches apart on a piece of cardboard and between these punch two holes just 1 inch apart. Hold the cardboard between the convex mirror and the sun and move it until the light which passes through the holes 1 inch apart is reflected to the dots 2 inches apart, and measure the distance from the back of the mirror to the card. This is the focal

Fig. 100. You find the focus hot

length of the convex mirror. Do you find it to be 2 inches?

There is no real focus for a convex mirror because it spreads the light, but the reflected rays appear to come from a point 2 inches behind the mirror. An unreal focus of this kind is called a **virtual** focus.

Fig. 101. You light a match with sunlight

Fig. 102. How to arrange cork, needle, and match

Experiment No. 62. Pictures. Go to the back of the room, turn the concave mirror toward the window, and hold a piece of paper three-quarters inch wide near the focus (Fig. 104). Do you find a small inverted picture in natural colors of the window and of the things outside the window?

Have a friend move about near the window. Do you get his picture?

Fig. 103. You light the match in the bottle

Fig. 104. You get a picture

Experiment No. 63. Your own image. Look at yourself in the concave mirror. Are you upside down and small? Bring your eye closer to the mirror than the focus (2 inches) (Fig. 105). Is your eye large and right side up? Look at yourself in the convex side. Are you small and right side up in all cases?

THE "WHY" OF THE CURVED MIRRORS

Waves. When parallel waves (1), Fig. 106, strike the concave side of the mirror, they are reflected and so **curved in** that they converge at the focus and then diverge.

When parallel waves strike the convex side (2), they are reflected and so **curved out** that they diverge and never meet.

Rays. The curved mirror is part of a sphere and the center of the sphere is at **C**, Fig. 107(1). The lines **CA** are radii of the sphere and they are perpendicular to the mirror. When parallel rays strike the concave mirror they make equal angles with these perpendic-

Fig. 105. Your eye is enlarged

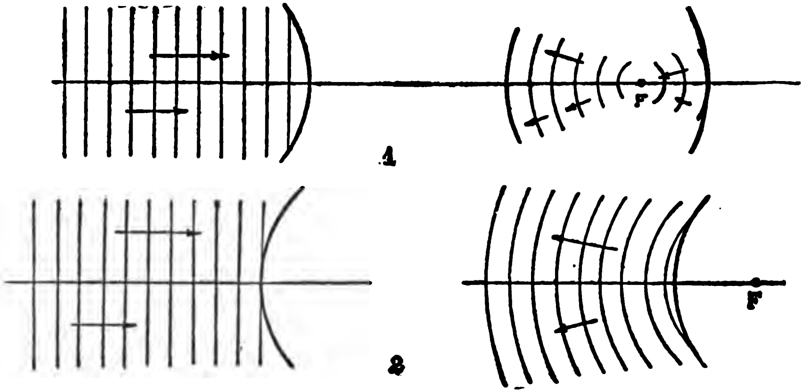


Fig. 106. (1) Parallel waves are curved in. (2) Parallel waves are curved out

ular radii and cross at the focus **F.** The line through the center **O** of the mirror and through the center **C** of the sphere is called the **principal axis** of the mirror. You will notice that the parallel

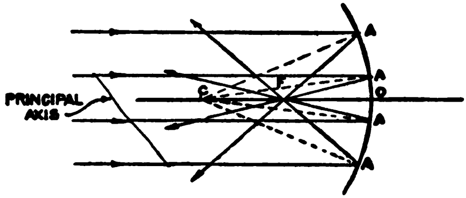


Fig. 107 (1). How parallel rays are converged by a concave lens and diverged by a convex lens

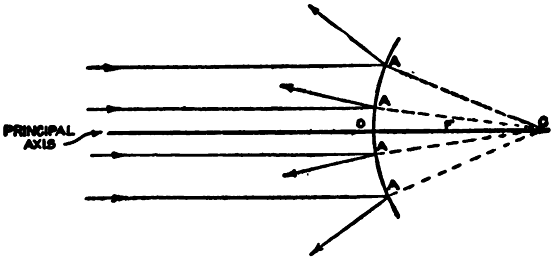


Fig. 107 (2)

Fig. 108. A searchlight
Courtesy of the Scientific American

rays which are above the principal axis before they strike the concave mirror are below it afterward and vice versa. This explains why the images you see in the concave mirror are reversed.

When your eye is nearer than the focus, it intercepts the rays before they can cross, and your image appears to be behind the mirror, right side up and large.

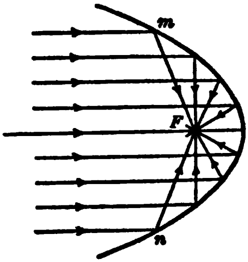


Fig. 109. A parabolic reflector
From Black and Davis' Practical Physics, published by The Macmillan Co.

When parallel rays strike the convex side of the mirror, Fig. 107(2), they make equal angles with the radii (CA extended); they diverge but appear to come from the focus **F**. This is the unreal or virtual focus.

The rays above the principal axis before reflection are above it afterward, and, therefore, the images in the convex mirror are right side up.

Searchlight Reflectors. The reflectors on battleship searchlights (Fig. 108) are made in the shape of a parabola (Fig. 109). Parallel rays which strike parabolic reflectors converge exactly at the focus, and conversely if a light is placed exactly at the focus the reflected light consists of parallel rays which go straight forward. The reflectors on automobile and locomotive headlights are also parabolic, and the lamp is placed at the focus.

Spherical Aberration. Spherical mirrors do not converge all parallel rays at the focus because those which strike near the edge are reflected behind the focus (Fig. 110). This is called the spherical error or spherical aberration of the mirror. Conversely if a light is placed at its focus a spherical mirror does not reflect it in parallel rays. This explains why it is not used as a first-class reflector.

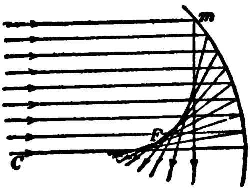


Fig. 110. The "why" of spherical aberration
From Black and Davis' Practical Physics, published by The Macmillan Co.

Fig. 111. The light is bent or refracted
From Lynde's Physics of the Household, published by The Macmillan Co.

REFRACTION OF LIGHT

When light passes in a slanting direction from one medium to another,—for example, from air to water or the reverse, or from air to glass or the reverse,—part of it is r e f l e c t e d at the surface between the two media and part of it enters the second medium but is bent out of its path, from **ABC** to **ABD,** Fig. 111. This bending is called **refraction.** When light passes from air to any denser medium as water or glass, it is bent **toward** a line **NN** drawn perpendicularly through the surface at the point it enters. See Fig. 112 (1). When l i g h t passes from water or glass to air, it is bent away from the perpendicular **NN.** See Fig. 112 (2).

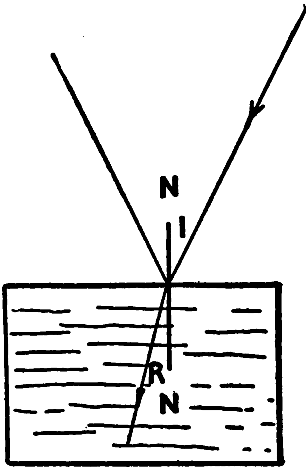


Fig. 112 (1). Part of the light is reflected and part refracted

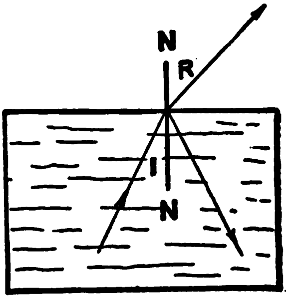


Fig. 112 (2)

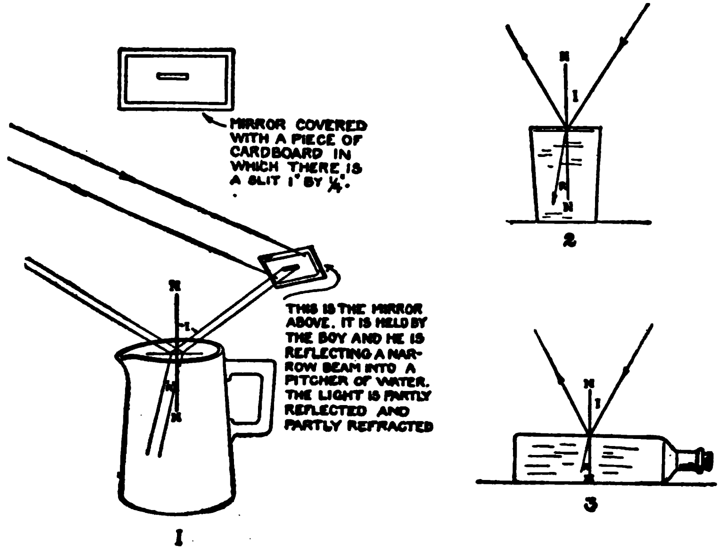


Fig. 113. You see light bent toward the perpendicular NN

FUN WITH SUNLIGHT

Experiment No. 64. Air to water. Allow a beam of sunlight to pass through the slit in your darkened room. Cut a slit 1 inch long and ¼ inch wide in a piece of cardboard, put this over your mirror, and reflect sunlight into a glass pitcher full of water into which you have put 2 or 3 drops of milk **(1)**, Fig. 113. Vary the slant of the beam of sunlight which strikes the water and view the beam in the water **through the sides** of the pitcher. Is some of the light reflected at the surface of the water? Does some of it enter the water and is it bent or refracted? Make the beam split on the side of the pitcher so that half is inside and half outside. Is the beam in the water bent **toward** an imaginary perpendicular at the point it enters? Repeat this with a glass of milky water **(2)**. Repeat with a bottle of milky water **(3)**. Use a bottle with flat sides.

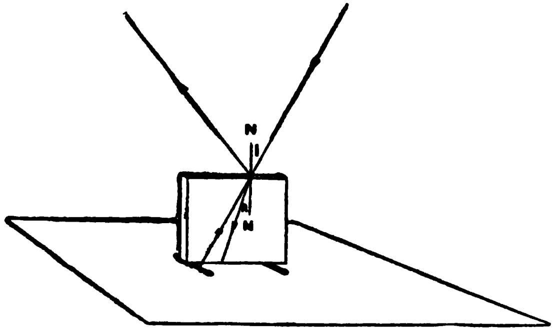


Fig. 114. You see part of the light reflected and part refracted

Experiment No. 65. Air to glass. Make the beam split on the thick glass plate standing on its edge, on two matches, on paper (Fig. 114). You cannot see the light in the glass but you can see it on the paper below after it has passed through the glass. Is the light which passes through the glass bent **toward** an imaginary perpendicular **NN** drawn at the point it enters?

Let the sunlight enter through a slit 1 inch long and ¼ inch wide. Split the beam of light on the edge of the glass plate and hold a piece of paper behind the plate. Tilt the plate to different angles. Is the light which passes through the glass plate always bent **toward** the perpendicular **NN?**

Experiment No. 66. A glass of water. Remove your shutter and stand a glass of water in sunlight near the window; fill the glass to the top and put paper around the sides to keep out the sunlight. Is the sunlight which strikes the water

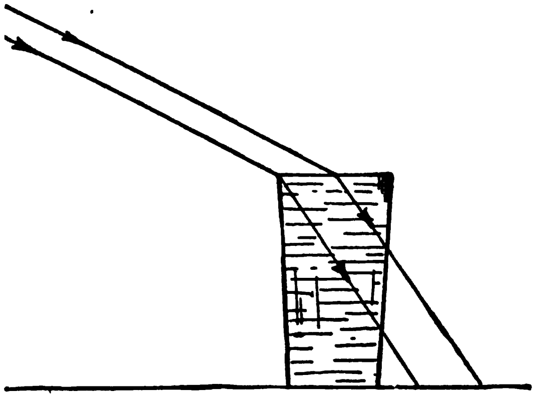


Fig. 115. The light is bent down

surface bent down, as shown in Fig. 115?

Explanation of Refraction. A beam of sunlight is bent or refracted when it passes from air to water because light travels more slowly in water than it does in air. Its velocity in water is only three-fourths of its velocity in air.

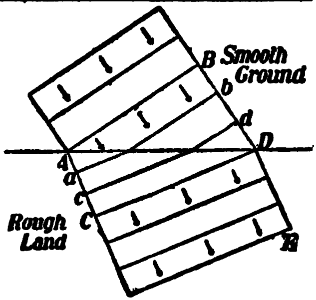


Fig. 116. The "why" of refraction *From the Ontario High School Physics, by permission of the publishers*

Now to see the connection between change in direction and change in velocity, let us consider what would happen if a regiment of soldiers marched in a slanting direction **BD** from smooth ground to rough ground, as shown in Fig. 116. The men would march less rapidly on the rough ground and the direction of the marching lines would be changed. The line **AB** is still on smooth ground and is straight. Part of the line **ab** is on rough ground and this part is somewhat behind. The line **cd** has a larger part on rough ground and this part is behind. The line **CD** is wholly on rough ground and it is marching in a direction **DE** different from **BD**, and it would continue in this new direction. This is exactly what happens to parallel light waves. They are bent **toward** the perpendicular when they pass at a slant from air to water or glass because they travel more slowly in water or glass than they do in air. They are bent **away from** the perpendicular when they pass at a slant from water or glass to air because they travel faster in air than they do in water or glass.

REFRACTION OF SPHERICAL WAVES

Experiment No. 67. A coin under water. Put a coin in a glass of water and look down at it through the water (Fig. 117). Does it appear to be nearer than it really is?

You see the coin because light passes from it to your eyes. This light is in the form of spherical waves in the water, but

Fig. 117. The coin appears closer to you than it is

when these waves enter the air they become more curved (see **BC**, Fig. 118) because the parts which enter the air first travel faster and get ahead of the parts still in water.

Now your eye estimates the distance of an object partly by the curvature of the waves which enter it from the object. The curvature of the waves which enter your eye from the coin is the same as though the coin were at a point **A** only three-fourths the depth, and this is the reason the coin appears to be at **A**.

If you look at the coin in a slanting direction, it appears to be nearer the surface still, because the light is bent more and more the greater the slant of the rays from the coin to the surface.

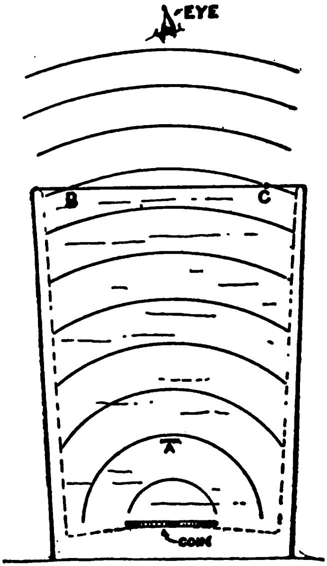


Fig. 118. Why the coin appears closer to you

RELATION BETWEEN ANGLES OF REFRACTION AND INCIDENCE

If the light ray in Fig. 119 is passing from air to water, then the line

RM is always exactly three-fourths the length of **IM** no matter how large or small i may be. If the light passes in the opposite direction, the same relation holds until the critical angle is reached. (See page 87 for definition of critical angle.)

If the ray is passing from air to glass, **RM** will always be two-thirds of **IM,** and this relation holds if the light passes from glass to air, until the critical angle is reached.

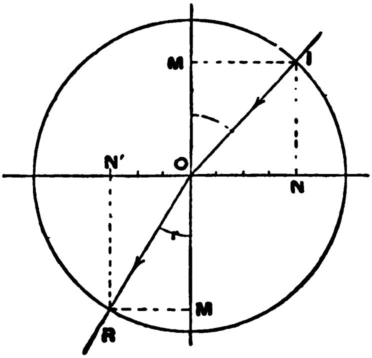


Fig. 119. RM is three-fourths of IM in water and two-thirds of IM in glass *From Lynde's Physics of the Household, published by The Macmillan Co.*

This gives you the relation between the angle of incidence and the angle of refraction in all cases.

FUN BY DAY OR NIGHT

Experiment No. 68. Magic lead pencil. Put a pencil in a glass of water in a slanting direction and sight along it (Fig. 120). Does it appear to be bent up? It does, because the light from it is bent as shown in Fig. 121.

Fig. 120. You see a bent pencil

Experiment No. 69. Magic ruler. Put a ruler vertically in a pitcher of water to a depth of 4

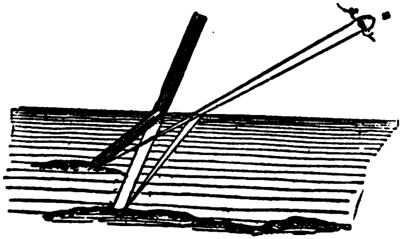


Fig. 121. The light is bent
From Black and Davis' Practical Physics, published by The Macmillan Co.

inches (Fig. 122). Does the part under water appear to be only 3 inches long when viewed vertically? It does, because light travels in water only three-fourths as fast as it does in air.

Does it appear much shallower when viewed at a slant? It does, because light is bent more the greater the angle at which it leaves the water.

Experiment No. 70. An elastic ruler. Shove the ruler to the bottom of a pail of water and lift it out. Does it appear to stretch?

Experiment No. 71. Magic glass. Stand a ruler at one end of the glass prism held on one edge, Fig. 123 (1). Does the bottom appear only two-thirds its real depth when viewed vertically? It does, because light travels only two-thirds as fast in glass as it does in air.

Does it appear even shallower when viewed at a slant? It does, because light is bent more the greater the angle at which it leaves the glass.

Repeat this with the prism on end.

Repeat with the glass plate on its edge, Fig. 123 (2).

Experiment No. 72. Phantom coin. Fill a long, deep pan with water. Put a coin on the bottom and view it vertically and then

Fig. 122. You see the ruler shortened in water

Fig. 123 (1). The prism and the glass plate appear shallower than they are

at greater and greater slants. Does the coin seem to rise? Why?

Experiment No. 73. A disappearing coin. Stand a coin on edge in a tin funnel full of water, ask a friend to stand so that he can just see the top over the edge of the funnel, and then let the water run out. Does he find that he can no longer see the coin from where he stands? Why?

Experiment No. 74. A broken looking-glass. Play this trick on your family. Take a piece of soap and mark a star with radiating lines near one edge of a looking-glass (Fig. 124). The family will think the glass is broken. A real break shows up because the light is refracted at the break and this gives a fair imitation.

Where is the Fish? The three boys **1, 2,** and **3** in Fig. 125 are looking at the same fish and they see it at the three different positions **1, 2,** and **3,** because the light from the fish is bent more the greater the slant it has when it reaches the water surface. None of them see the fish where it is.

Fig. 123 (2)

Fig. 124. A broken mirror

How Deep is the Water? If you have gone swimming in very clear water you know that it always looks shallower than it is. If the water is at the same depth everywhere it will look to you shallower in the distance, for the reasons given above.

How Tall are You to a Fish? If you are 6 feet tall a fish (Fig. 126) sees you as 8 feet tall, because the curved waves from you are made less curved in water and, therefore, appear to come from a more distant point.

Experiment No. 75. Breaking a pencil without touching it. Look at a pencil in a slanting direction through a bottle of water with flat sides or through the edges of the glass plate. Does it appear to be broken into three parts? Why?

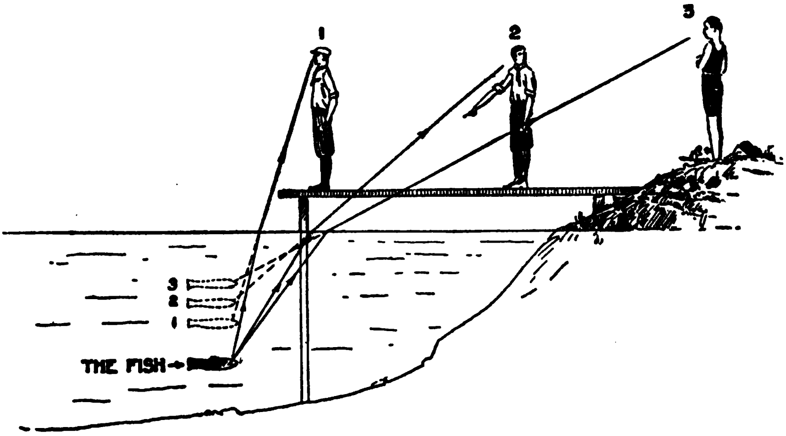


Fig. 125. They see the fish at different depths

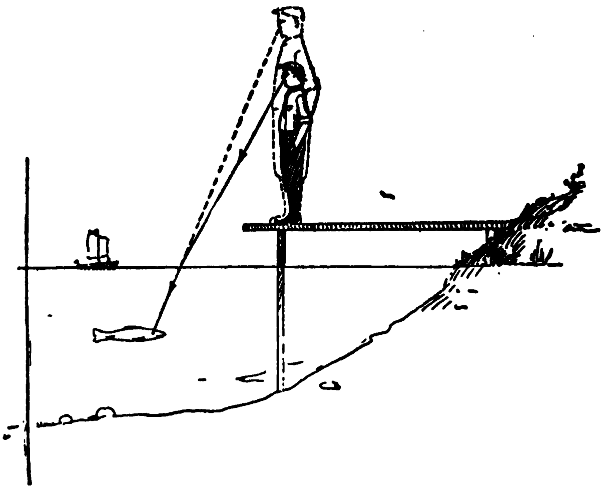


Fig. 126. You appear to a fish to be four-thirds bigger than you are

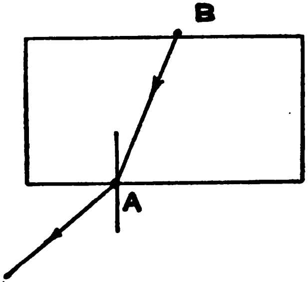


Fig. 127. The light bends at A

Experiment No. 76. Shifting pin. Put the glass plate flat on a piece of paper on the table. Stick the pins **A, B** on each side (Fig. 127) and sight from pin **A** to **B** through the glass. Does **B** appear to be shifted? Draw lines around the edges of the plate, aim a ruler at the two pins through the glass, and draw a line along the ruler; then draw a line from **B** to **A** and draw a line perpendicular to the edge of the plate at **A.** This shows that the light which passes from **B** to **A** in glass is bent away from the perpendicular when it enters air.

Experiment No. 77. Shifting line. Put the plate on a piece of paper (Fig. 128) and draw lines around the edge. Now draw a slanting line **AB,** sight along a ruler through the glass at this line, and draw the line **CD** along the ruler. Is the line parallel to **AB** but shifted? Draw perpendiculars at **B** and **C** and draw a line from **B** to **C.** The light from **A** passes into the glass at **B** and is bent **toward** the perpendicular at **B**; it passes from glass to air at **C** and is bent **away from** the perpendicular at **C.**

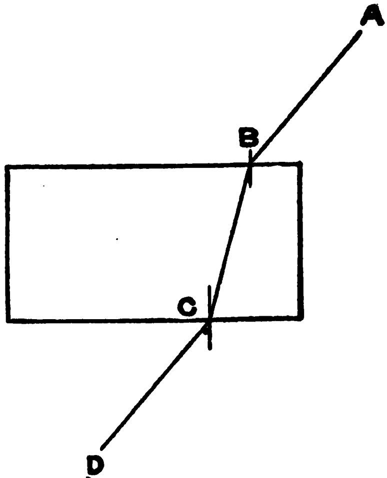


Fig. 128. The light bends at B and C

Experiment No. 78. Things are not where they seem. Look at a lighted candle through your glass prism (Fig. 129). Does the candle appear to be in a different place?

Does it also appear to be


Fig. 129. You see a shifted candle

beautifully colored? You will experiment with colors soon.

Experiment No. 79. Bending light around a corner. Stand the prism on end on paper and draw a triangle around the end (Fig. 130). Now draw a line **AB** slanting toward one side. Sight along a ruler through the prism at this line and draw a line **CD** along the ruler. Now remove the prism, draw short perpendiculars at **B** and **C**, and join **BC**.

The light from **A** enters glass at **B** and is bent **toward** the perpendicular; it enters air again at **C** and is bent **away from** the second perpendicular. This is why the light is bent around a corner by your prism.

Experiment No. 80. To see under water from a boat. You cannot see things under water from air usually, because the light reflected from the surface blinds you to the light coming from beneath the surface. You can easily see through the sur-

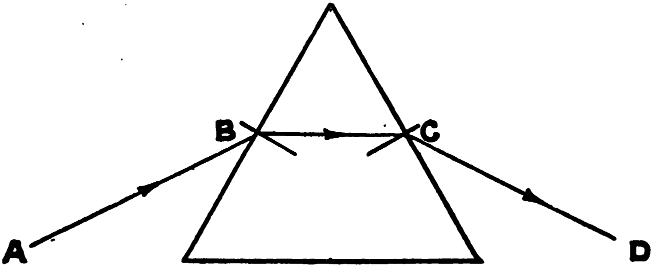


Fig. 130. The light bends around a corner

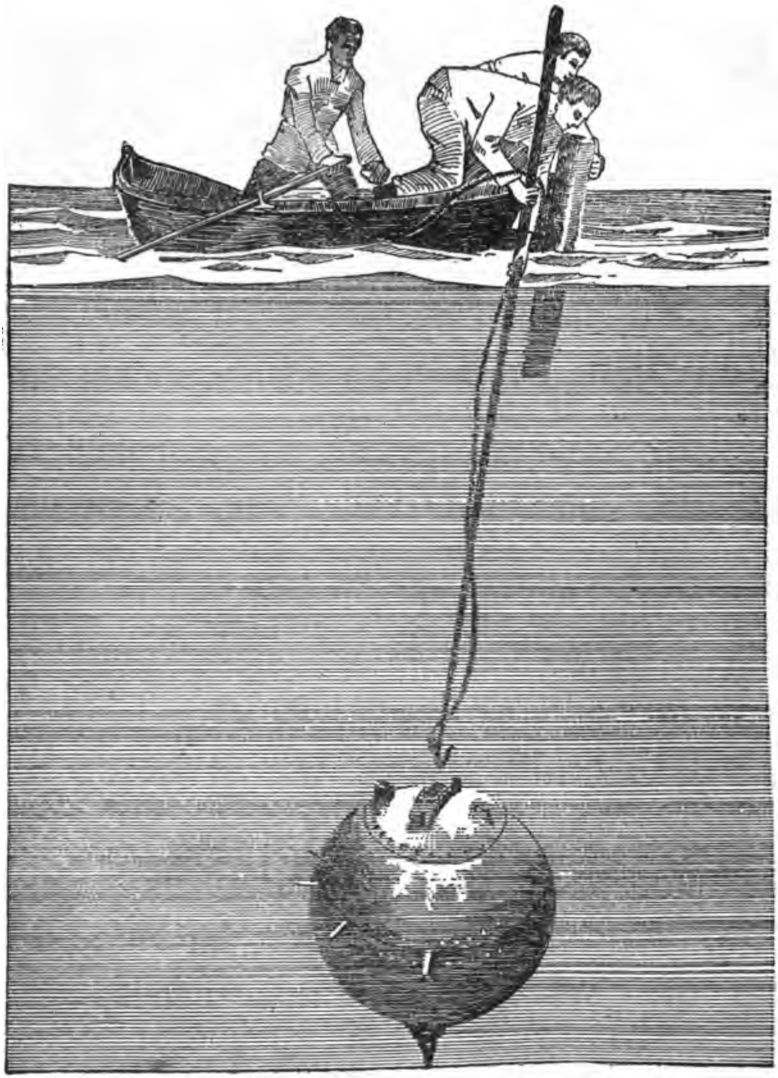


Fig. 131. You can see under water through a tube

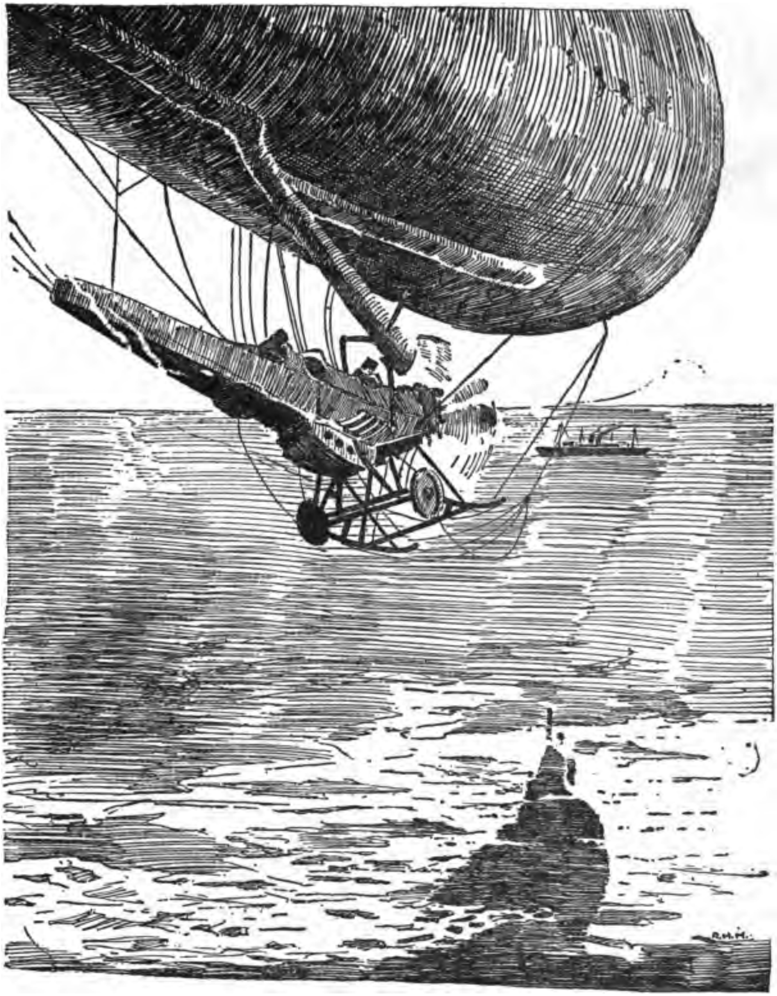


Fig. 132. Spotting submarines

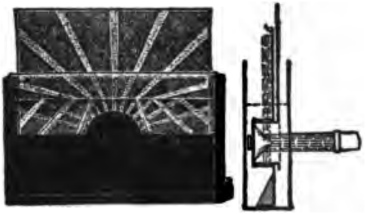


Fig. 133. How light passes from water to air
From Black and Davis' Practical Physics, published by The Macmillan Co.

face, however, through a pipe of any kind, as shown in Fig. 131, because the sides of the pipe keep the reflected light out of your eyes. Try this with a pipe 2 or 3 feet long.

Experiment No. 81. To see the fish you are trying to catch. If you can fish under a boathouse or under a wharf, you can see the fish deep down under water because the house or wharf prevents surface reflection. You can do this also as follows: Stretch a blanket or tarpaulin between two boats and put your head under it. The surface reflection is removed and you will be able to see to great depths.

Spotting Submarines. Submarines are easily spotted at great depths from a dirigible or airplane at a great height above the surface (Fig. 132) because at these great heights the light re-

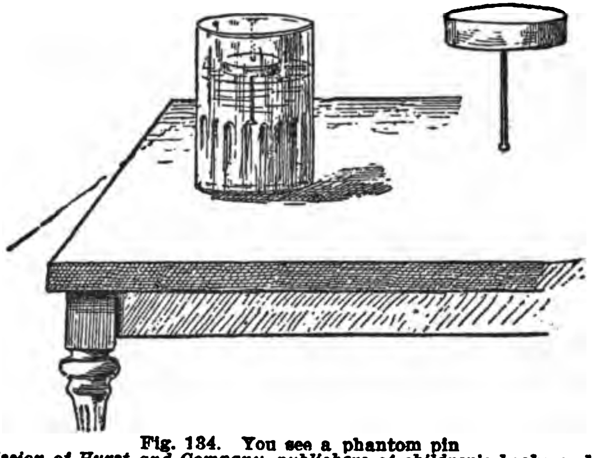


Fig. 134. You see a phantom pin
Permission of Hurst and Company, publishers of children's books and toys

flected vertically upward is not so great as the vertical light received from objects beneath the surface.

Total Reflection. When light passes from water to air in a slanting direction (Fig. 133), part of it is reflected and the part which passes through is bent away from the perpendicular. As the slant becomes greater the bending is greater, and finally the light which passes into air is at right angles to the perpendicular. If the light in water is still more slanting when it reaches the surface, it does not pass into air at all, but is all reflected back into the water. This is called **total reflection.** The angle at which this takes place in water is any angle greater than 48.5°, and in crown glass and hard flint glass, any angle greater than 41° and 37° respectively. These angles are called the **critical angles** for these substances.

Experiment No. 82. A phantom pin. Cut a slice of cork, attach a pin to the under side, float the cork on the surface of water in a full glass, stand the glass on the table, and look at the cork from the level of the table. Can you see a phantom pin **above** the cork (Fig. 134)? You see it by means of light reflected from the under side of the water surface.

Experiment No. 83. A broken spoon. Put a spoon in a glass half filled with water and look at the under side of the water surface through the side of the tumbler. Do you find a brilliant image of the part of the spoon in water? You see this by light reflected at the under surface.

Prism Glass. These prism glasses, Figs. 135 (1) and (2), are used to throw light to the rear of a store, or from the sidewalk into the basement. They are made of glass and have prisms on one side. The light which enters them is totally reflected from the inside surface

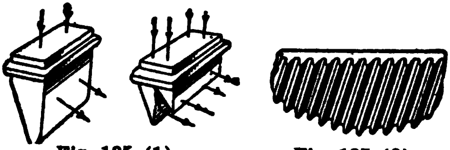


Fig. 135 (1) Fig. 135 (2)
Light is reflected from inside surface of prism
From the Ontario High School Physics, by permission of the publishers

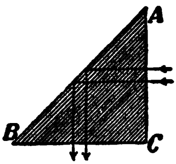


Fig. 136. A right-angled prism

of the prisms and is directed to the back of the building or basement.

Right-angled Prisms. These are made of glass and act as mirrors, in some opera glasses and other optical instruments. Light which enters one right-angled face, **AC**, Fig. 136, is totally reflected at the slanting face and passes out through the other right-angled face **BC.**

ATMOSPHERIC REFRACTION

Mirages. A ship at sea sometimes appears upside down (Fig. 137) because the air near the cold water is colder and denser than the air above and the light from the ship is refracted as it passes from each layer of cold air to the warmer layer above and is finally totally reflected. The light which enters the sailor's eye appears to come from the image above.

Mirages on the hot deserts are caused by light from the

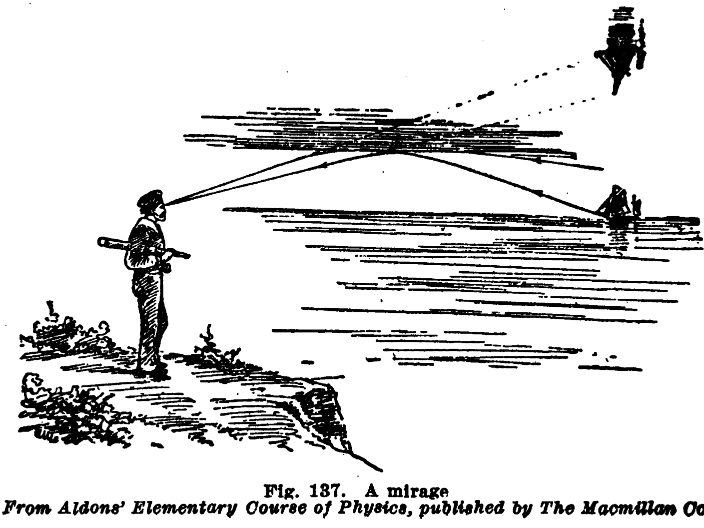


Fig. 137. A mirage
From Aldons' Elementary Course of Physics, published by The Macmillan Co.

clouds which passes from the upper cold air through warmer and warmer lower layers. It is refracted and finally totally reflected and the clouds look like a lake of water on the ground.

Sunset and Sunrise. You see the sun before it is up and

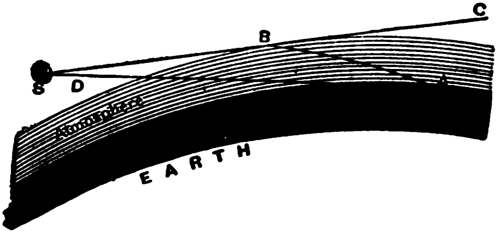


Fig. 138. Why you see the sun before it rises and after it has set
From Appleton's School Physics, published by the American Book Co.

after it has set because light from it is refracted by successive layers of air which are denser the nearer they are to the earth.

The direct ray **SD,** Fig. 138, could not be seen at **A** because the earth is in the way, but the light **SB** is seen because it is refracted to **A.**

COLOR

Spectrum. When a beam of sunlight passes through a glass prism as shown in Fig. 139, it is spread out into a colored band called the **spectrum.** This spectrum contains all the primary colors, of which those most easily recognized are in order: red, orange, yellow, green, blue, indigo, and violet.

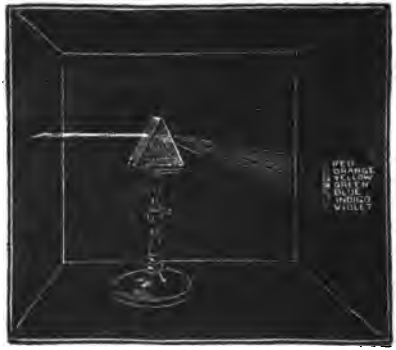


Fig. 139. A prism produces a spectrum from white light
From Lynde's Physics of the Household, published by The Macmillan Co.

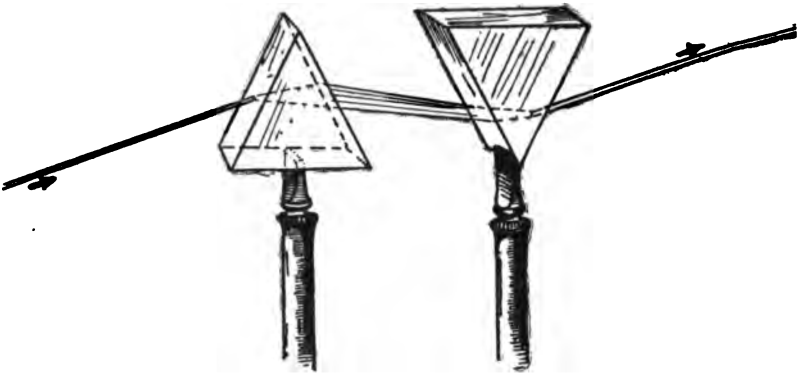


Fig. 140. A spectrum recombined to produce white light

White Light made up of all Colors. The experiment above shows that white light is made up of lights of all primary colors. This is proved again by passing the spectrum through a prism turned in the opposite direction (Fig. 140); the colors are recombined to produce white light.

Fig. 141. White light is made up of many primary colors
Courtesy of the Scientific American

It can be proved also by turning the prism back and forth quickly (Fig. 141). The colors overlap at the center and produce white light.

Dispersion. You know that light is refracted or bent when

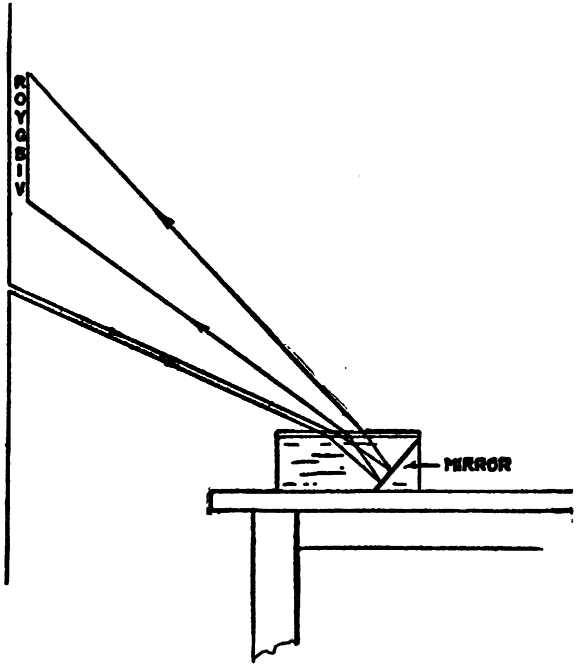
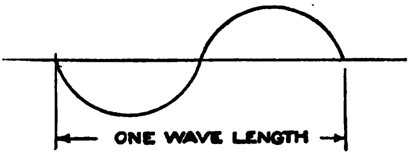


Fig. 142. A beautiful spectrum by reflection under water

it passes from air to water or glass or the reverse, because it travels more slowly in water and glass than it does in air. Now the waves of red light are longer than those of orange, the waves of orange are longer than those of yellow, and so on, the waves of each light beginning at the red end of the spectrum are longer than those next to it until we get to the very shortest, namely, the waves of violet light. It has been found by experiment that the shorter the waves, the more slowly they travel in water or glass and, therefore, the more they are refracted or bent when they pass from air to water or glass, or the reverse. When white light passes through a prism then, the shorter waves are bent



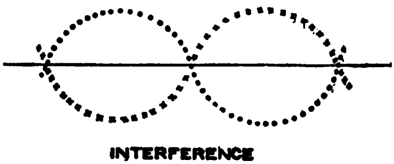


Fig. 143. The waves destroy each other or interfere

or refracted more than the longer waves and as a result the white light is spread out into the spectrum. This spreading of light is called **dispersion.**

Spectrum by Reflection. Another beautiful method of producing a spectrum is illustrated in Fig. 142. A mirror is placed in a slanting position under water in a pan and a beam of sunlight is allowed to fall on the mirror. The sunlight, in going through the water to the mirror and back, really passes through a prism of water and it is spread out or dispersed into a beautiful spectrum.

If, after the spectrum is formed, the surface of the water is stirred, the colors of the spectrum are mixed and the reflected beam is white. This proves again that white light is made up of all the colors of the spectrum.

Interference. In a water wave the particles of water simply move up and down, but the wave moves forward. A wave length is a hill and a hollow.

If, now, two waves of exactly the same length come together in such a way that one is one-half wave behind the other (Fig. 143), the hill of one coincides with the hollow of the other, the particles of water do not move at all, and one wave destroys the other. This is called **interference.**

The same thing occurs in light waves; two streams of waves may come together and destroy each other, that is, produce darkness.

Fig. 144. Colors in a soap film

Colors by Interference. If a beam of sunlight is allowed to fall on a soap film held in a vertical position on the end of a lamp chimney (Fig. 144), it is found that the soap film when viewed by reflected light is crossed by horizontal colored bands. These colors are formed by interference as follows: The soap film has two surfaces with water between, and when it stands on edge the water runs toward the bottom and the film becomes a narrow prism. Now the light is reflected partly from the front film and partly from the back film, and where the films are 1-4, 3-4, 5-4 waves of red light apart, the red waves from the rear are 1-2, 1 1-2, 2 1-2 waves behind the red waves from the front when they enter your eye. These two sets of waves, then, interfere and destroy each other, and all that your eye sees is blue. Similarly a little above and below these points the blue waves destroy each other, and you see red light.

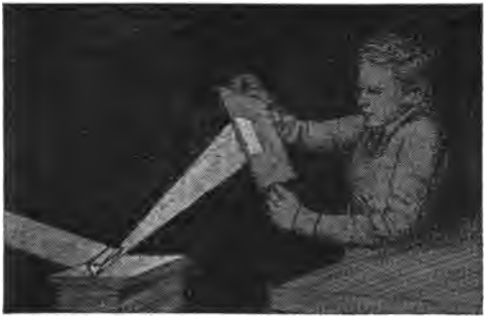


Fig. 145. You produce a beautiful spectrum by means of your prism

FUN WITH SUNLIGHT

Experiment No. 84. The prism spectrum. Allow a beam of sunlight to pass through

Fig. 146. You produce a beautiful spectrum by reflection under water

the slit in your darkened room and fall on the prism supported between blocks as shown in Fig. 145. Cut a piece of cardboard of the exact size of one face of the prism and put it on the upper face. Do you find a beautiful spectrum on the wall or ceiling? Do you find that the violet end is nearest the base of the prism and the red end nearest the angle, that is, is the violet end the most bent? Turn the prism over. Do you get a spectrum on the floor?

Get the spectrum on the wall or ceiling again and rock the prism quickly. Is the center of the spectrum white? This proves that white light is made up of all spectrum colors because they mix at the center.

Experiment No. 85. Spectrum by reflection. Place a mirror in a slanting position under water and arrange it so that the beam of sunlight falls on the mirror (Fig. 146). Do you find a beautiful spectrum on the wall above the slit? Stir the water. Do the colors mix and produce white light?

Experiment No. 86. Colors by interference. Make soap suds as you would for blowing soap bubbles. Put the suds in a saucer. Dip the end of a lamp chimney in the suds and support the chimney on its side in sunlight (Fig. 144). Look at the film by reflected light. Do you find that the film at the top is crossed by beautiful horizontal colored bands? These colors are produced by interference. The colors in a soap bubble and in a film of oil on water are produced by interference.

WHY OBJECTS ARE COLORED

An object has a certain color because something in the object absorbs all other colors. For example, a blue dress is blue because the dye in the dress absorbs all the other colors of the spectrum. Also a red dress is red because the dye absorbs the colors in the blue end of the spectrum, and so on.

An object is white when all of the colors of the spectrum are partly absorbed and all are reflected.

An object is black when all the colors are completely absorbed and none reflected.

Experiment No. 87. Changing colors. Darken your room and allow sunlight to enter through a slit smaller than your colored-glass plates. Hold the red glass over the slit and hold colored objects in the red light. Are red objects red, but all other colored objects dark or black? They are dark or black because the dye in them absorbs the red light. Repeat with the blue glass. Are the results similar?

Note. The blue glass lets through a little red, yellow, and green, as you will now show.

Experiment No. 88. Changed spectrum. Get the spectrum with the prism and then put the red glass against the prism. Does the red glass absorb all colors except red? Repeat with the blue glass. Does it absorb nearly all colors except blue, but does it let through a small amount of the other colors?

Experiment No. 89. Changing colors in spectrum. Get the spectrum with the prism and hold colored objects in the different colors. Do they change colors according to the part of the spectrum they are in? They are black in the part of the spectrum which they absorb completely.

FUN BY DAY OR NIGHT

Experiment No. 90. A colored strip. Cut a strip of white paper about 1-16 inch wide and 2 inches long and pin it to a

Fig. 147. The white paper is colored

black object. Put it in a good light and look at it through the prism (Fig. 147). Do you find a spectrum instead of the white paper?

Do you find also that the spectrum is reversed, that is, that the red is nearest the base of the prism and the violet nearest the angle? This is so because your eye sees an object in the direction the light enters it from the object. The red is least bent but appears to be most bent, and the violet the reverse.

Experiment No. 91. Combining spectra. Cut a strip of white paper 1 inch wide and 2 inches long and look at it through the prism (Fig. 148). Do the edges appear colored, but is the center white? The center is white because the spectra formed by the edges overlap at the center and this combination of all the colors of the spectrum produces white light.

Experiment No. 92. Colored candle flame. Look at the flame of a candle through a prism. Is it beautifully colored, but does the center tend to be white and are the colors reversed as above?

Fig. 148. The paper is colored only at the edge

COMPLEMENTARY COLORS

Complementary colors are those which, when combined, produce white light. If any colors are taken out of the spectrum, the remaining colors are complementary to those taken out, because together they produce white light.

MIXING PAINTS

A paint which absorbs the colors in the blue end of the spectrum is red in color and a paint which absorbs the colors in the red end of the spectrum is blue in color. If, now, these paints are mixed, they do not produce white paint but black paint because together they absorb all the colors.

FUN WITH SUNLIGHT

Experiment No. 93. Colored glasses. Stand the red and blue glasses side by side on a piece of white paper in sunlight. The red absorbs the blue end of the spectrum and lets through red light. The blue absorbs the red end of the spectrum and lets through blue light. Now place one behind the other. Do they absorb all the light and is the shadow black?

THE RAINBOW

The rainbow (Fig. 149) is formed by the internal reflection and dispersion of sunlight by falling drops of water. You see it when the sun is behind you and not over 42° above the horizon. The first or primary rainbow is formed by two refrac-

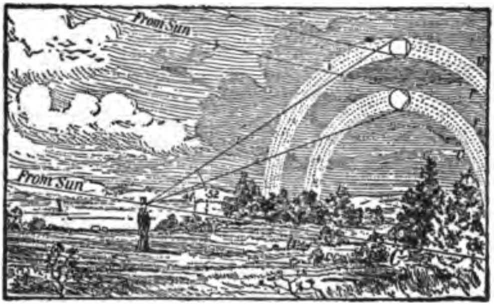
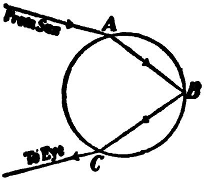


Fig. 149 (1). The "why" of the rainbow
From the Ontario High School Physics, by permission of the publishers



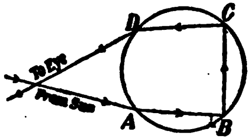


Fig. 149 (2) Fig. 149 (3)
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tions at **A** and **C** and one internal reflection at **B** (2); it is violet below and red above and the angle at which the light enters your eye is about 41° to the direction of the sunlight. The secondary rainbow is formed by two refractions **A** and **D** and two internal reflections **B** and **C** (3); it is red below and violet above and the angle of the light is about 52°.

Experiment No. 94. An artificial rainbow. Place a glass full of water (Fig. 150) on a table in sunlight and projecting beyond the edge. Do you get two or more beautiful rainbows on the floor? Stand the glass on a mirror. Do you get two beautiful rainbows on the ceiling? These bows, however, are not reversed. This

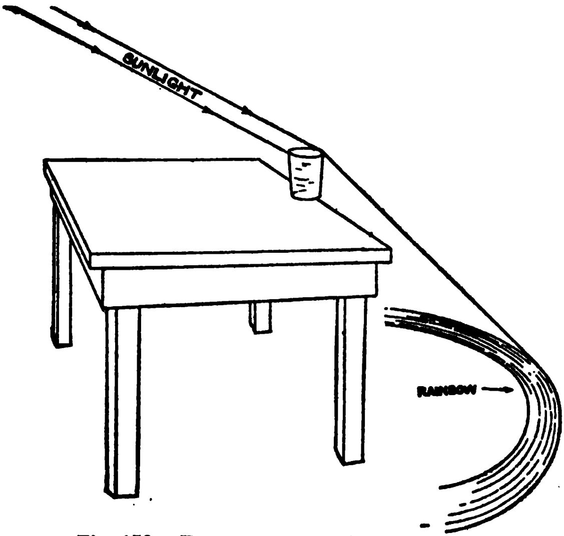


Fig. 150. You make an artificial rainbow

experiment will show best in your darkened room.

Fig. 151. You see a devil

FUN AT NIGHT

Experiment No. 95. A changing devil. Cut a little devil out of cardboard and arrange as shown in Fig. 151. Hold the red glass in front of the candle at the right. Is the devil at the right red and is the devil at the left very dim but of the complementary color, green? Use blue glass. Is one devil blue and the other very dim but of the complementary color, orange?

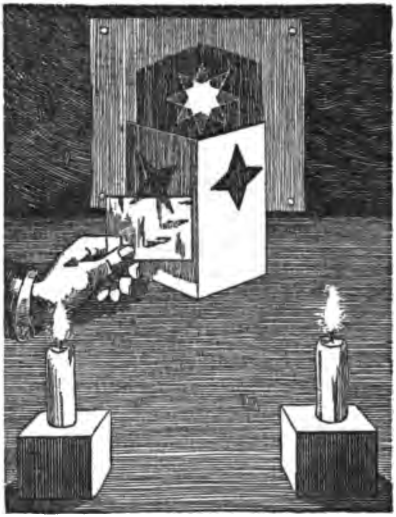


Fig. 152. You see an eight-pointed star

Experiment No. 96. A tri-colored star. Fold a piece of cardboard. Cut a four-pointed star in one half. Fold the points back, make a tracing on the other half, and cut out a star very carefully with the points exactly between those of the first. Arrange as shown in Fig. 152 and hold the red glass in front of one candle. Do you get an eight-pointed star with the points alternately red and green and with a white or pink eight-pointed star inside? Repeat with the blue glass. Are the points blue and orange?

Fig. 153. Trench faces

Experiment No. 97. A ghost party. Mix a half teaspoonful of salt in three or four teaspoonfuls of alcohol in a saucer, stand the saucer on a cup on the table (to prevent burning the table),

seat the party around the table in the dark, light the alcohol, and look at your neighbors' faces and at your own in a mirror. Do you all look like ghosts? You do, because the salt in the flame gives only yellow light, and since your rosy cheeks and rosy lips absorb this color they appear black.

TRENCH FACES

Our boys at the front painted their faces black (Fig. 153) before they started out on night raids, because the black paint absorbed the light and prevented their faces from being seen.

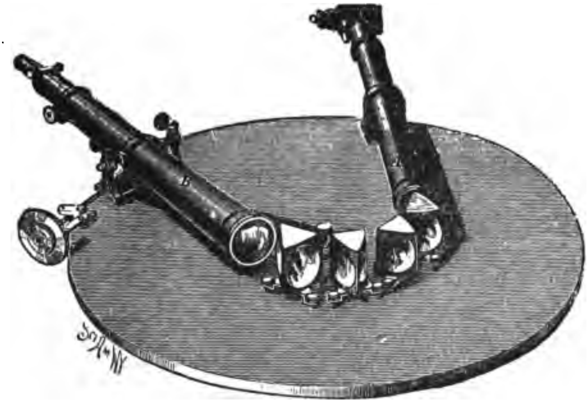


Fig. 154. Spectroscope
Courtesy of the Scientific American

THE SPECTROSCOPE

When substances are vaporized in a flame and the flame is viewed through a spectroscope (Fig. 154) the spectrum seen is crossed by bright lines. Each substance has its own particular lines, and when we know these lines we can tell what substances are in the flame. This is the basis of spectrum analysis. In the spectroscope shown here the light passes through a narrow slit, through tube **A**, through four prisms, and into the telescope **B** in which the enlarged spectrum is seen.

WHAT IS IN THE SUN AND STARS?

When the light from the stars is viewed in the spectroscope, the spectrum is crossed by dark lines exactly corresponding to the bright lines mentioned above. These are called the Fraunhofer lines, after their discoverer. If, in the spectrum of light from the sun, for example, we see dark lines exactly corresponding to the bright lines produced by iron in the spectrum on the earth, we know that there is iron in the sun, and so on.

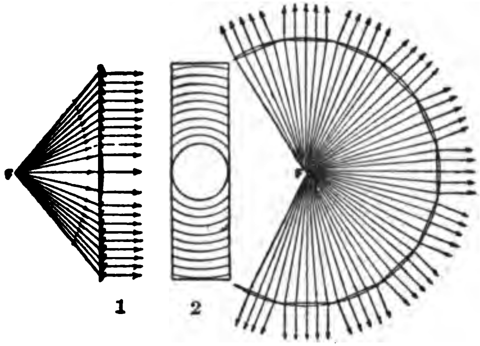


Fig. 155. A lighthouse lens
From Aldons' Elementary Course of Physics, published by The Macmillan Co.

LIGHTHOUSE LENSES

Lighthouse lenses have at the center a comparatively thin lens and around this prismatic sections with greater and greater angle toward the edge, (1) Fig. 155. Panels (2) made up in this way are placed completely around the light **F** (3). This gives a large, short focus lens which does not absorb as much light as a solid thick lens would absorb.

LENSES

Lenses are of two kinds, converging and diverging.

Converging lenses are thicker at the middle than at the edges, and we may think of them as made up of sections of prisms,

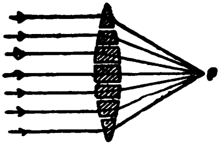


Fig. 156 (1). A converging lens as sections of prisms

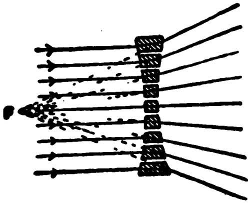


Fig. 156 (2). A diverging lens as sections of prisms

From Lynde's Physics of the Household, published by The Macmillan Co.

Fig. 156 (1), the angles of the prisms being greater the nearer they approach the edges. These lenses converge parallel rays to a point F, called the focus.

Diverging lenses are thinner at the middle than at the edges, and we may think of them as made up of sections of prisms, Fig. 156 (2), with their thin edges toward the center. These lenses diverge parallel rays and make them **appear** to come from a point F, called an unreal or virtual focus.

FUN WITH SUNLIGHT

Experiment No. 98. Converging lenses. Allow sunlight to pass through the slit in your darkened room, hold a converging lens in the beam (Fig. 157) and make a dust. Do you see that the light comes to a point and diverges afterward?

Repeat with the other converging lens. Is the light again brought to a point but at a different distance from the lens?

Fig. 157. You see a brilliant focus in dusty air

Fig. 158. You measure the focal length

Experiment No. 99. Diverging lens. Repeat this experiment with your diverging lens. Is the light diverged or spread?

Experiment No. 100. Focal lengths. Remove your shutter, focus the light with a converging lens, hold a piece of paper at the point where you get the smallest and brightest image of the sun (Fig. 158) and measure the distance from the lens to the paper. The point is the focus and the distance is the focal length of the lens.

Repeat with the other converging lens.

Do you find the focal lengths of the lenses to be 4 inches and 8 inches respectively?

Experiment No. 101. Focal length of diverging lens. Punch two nail holes exactly 1 inch apart in a piece of paper, put this in front of the diverging lens, and measure the distance at which the spots of sunlight appear 2 inches apart on a paper behind the lens. This is the virtual focal length. Is it 4 inches?

Experiment No. 102. Is it hot? Put your hand at the focus of each converging lens in turn (Fig. 159). Is the sunlight hot? It is, because all the light and heat

Fig. 159. The focus is hot

which falls on the lens is concentrated at the focus.

Repeat with the diverging lens. Is there no heat?

Experiment No. 103. To light a match with sunlight. When the sun is hot at mid-day put a match on a piece of paper and focus sunlight on it with the short focus lens (Fig. 160). Does it light? Why?

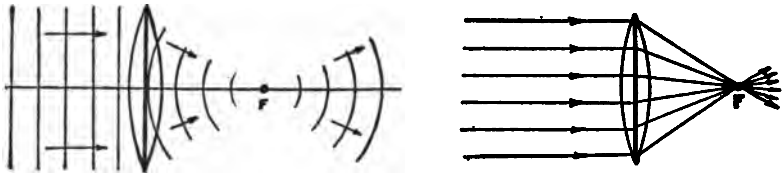
Fig. 160. You light a match with sunlight

Experiment No. 104. Magic cannon. Repeat Experiment No. 59, but light the match by means of the short focus lens (Fig. 161).

THE "WHY" OF IT

When the parallel waves from the sun fall on a converging lens, which is thicker at the middle than at the edges (Fig. 162), the portions of the waves that go through the thick part are slowed up more than the portions which go through the thinner parts, and as a result the waves are so **curved in** that they converge at the focus and diverge afterward. The waves are shown

Fig. 161. You light the match in the bottle



1 2

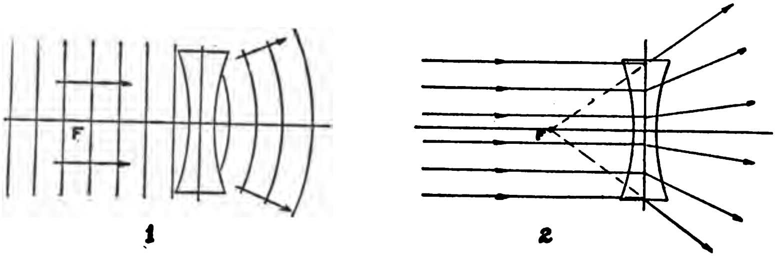
Fig. 162. Parallel waves and rays are converged

in **1** and the rays in **2**. This explains why these lenses converge the light.

When parallel waves fall on a diverging lens, which is thinner at the center than at the edges, the portions which go through the center are less delayed than the portions which go through the edges and the waves are so **curved out** that they diverge after passing through the lens. The waves are shown in **1**, Fig. 163, and the rays in **2**. This explains why these lenses diverge the light.

If the light comes from an object near a converging lens the waves are curved when they reach it, and one of three things may happen.

If the object is at a distance from the lens greater than the focal length (**1**, Fig. 164), the curvature of the waves is reversed and the light is brought to a point on the other side of the lens



1 2

Fig. 163. Parallel waves and rays are diverged

at a distance greater than the focal length.

If the light is at the focus (2, Fig. 164), the curvature of the waves is so altered that they are parallel after they pass through the lens.

If the light is nearer to the lens than the focus (3, Fig. 164), the curvature of the waves is altered by the lens, but they still diverge and will never converge.

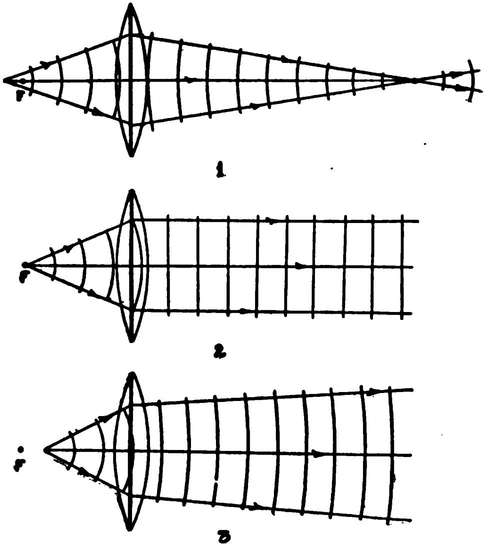


Fig. 164. Light and a converging lens

FUN BY DAY OR NIGHT

Experiment No. 105. Images. Arrange a candle, 4-inch converging lens, and screen as in Fig. 165. Place the lighted candle 3 feet from the lens and move the screen until you get an image. Is it inverted and small? Repeat with candle at 2 feet and 1 foot. Is the image larger each time?

Fig. 165. You see a picture of the candle

Place candle at twice the focal length, that is, 8 inches. Are image and candle the

Fig. 166. You see a picture of your hand

same size? Place candle at 6 inches. Is the image larger? Place candle at 5 inches. Is the image larger still? Place candle at the focus. Is the image very large? Place candle at 3 inches and 2 inches, that is, closer than focus. Are no images formed?

Repeat with the converging lens of 8-inch focus. Place candle at distance of 4 feet, 3 feet, 2 feet, 16 inches or twice the focal length, 15 inches, 12 inches, 8 inches, and 6 inches. Are the results similar?

Is the image smaller than the candle when the candle is at a greater distance from the lens than twice the focal length? Is it larger when the candle is at a distance less than twice the focal length and greater than the focal length?

Experiment No. 106. Picture shows. With the candle, converging lens, and screen, as in Fig. 166, get the image of the candle on the screen, then hold your hand behind the candle and close to it. Do you get an inverted picture of your hand in natural colors?

Hold a black and white drawing upside down and close to the candle. Do you get a picture right side up?

Repeat with colored drawings, colored flowers, and so on. Do you get colored pictures?

Repeat with all kinds of things and use four or five candles to get more light.

Experiment No. 107. A picture of out-of-doors. In the daytime, go to the side of the room away from the window and get a picture of distant objects on the screen (Fig. 167). Do you

Fig. 167. You see a picture of things out-of-doors

find a beautiful inverted picture in natural colors of everything out-of-doors?

Measure the distance from lens to screen. This is again the focal length of the lens. At night get a picture of a distant light and measure the focal length.

Experiment No. 108. The lenses and your eyes. Hold the converging lenses in turn at arm's length and look at distant objects. Is the image small and inverted?

Hold them about one foot from your eye and look at your finger held closer to the lens than its focal length. Is the image large and right side up?

Repeat with the diverging lens. Is the image always right side up and small?

HOW THE IMAGES ARE FORMED

In Fig. 168 (1) the object **OB** is at a greater distance than the focal length. All the rays which fall on the lens from any point **B** meet at the point **M** and, therefore, the image of **B** is at **M**. We cannot trace all the rays, but it is necessary to trace only two. The two most easily traced are the parallel ray **BR** and the ray **BP** which goes through the center of the lens. Ray **BR** goes through the focus **F** after it goes through the lens; ray **BP** goes straight ahead, or nearly so, because the two sides of the lens are nearly parallel at the center.

The rays from all other points between **B** and **O** meet at points between **M** and **I** and, therefore, **MI** is the inverted image of **BO**.

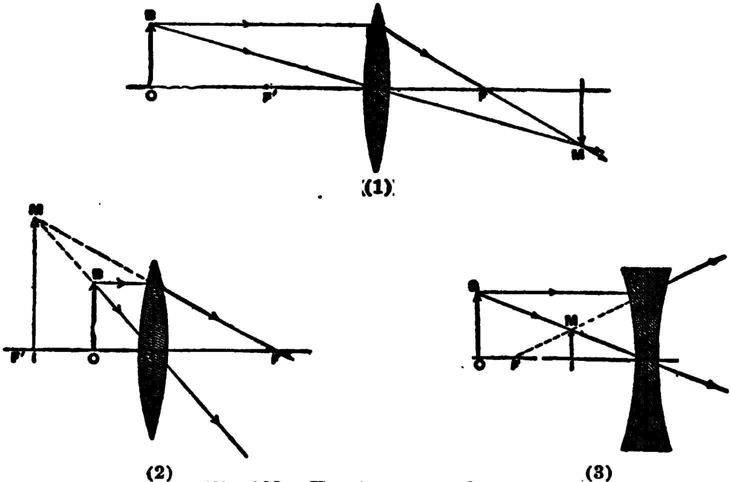


Fig. 168. How images are formed
From Lynde's Physics of the Household, published by The Macmillan Co.

In (2), **BO** is inside the focus; therefore **BR** and **BP** diverge after they pass through the lens and do not form an image. Your eye, however, makes an image because it sees the rays as though they came from **MI**. This explains why you see anything inside the focal length as enlarged and right side up.

In (3), **BO** is outside the virtual focus of the diverging lens. **BR** and **BP** diverge after they pass through the lens and your eye sees the image **MI**. This explains why diverging lenses always give images small and right side up.

POWER OF A LENS

Spectacles are lenses, and opticians measure the power of the spectacle lenses as follows: If the lens has a focal length of 1 meter it is said to have a power of 1 **diopter**; if it has a focal length of 1-2, 1-3, or 1-10 meter it is said to have a power of 2, 3, or 10 diopters; and so on. That is, the shorter the focal length the greater the power.

A meter is 100 centimeters long. You will find on most ordinary rulers 30 divisions on the side opposite the inch divisions;

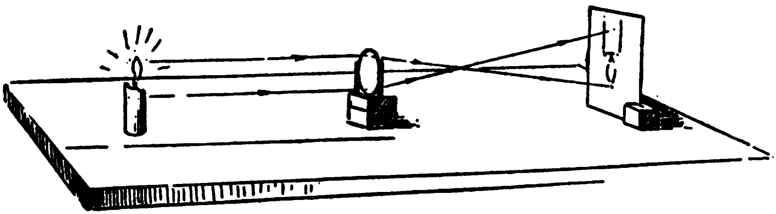


Fig. 169. Conjugate foci

each of these divisions is 1 centimeter, and 100 of these make a meter.

Experiment No. 109. Power of your lenses. Measure in centimeters the focal length of the 8-inch lens. Do you find it to be 20 cms.? Is the power of the lens then $\frac{100}{20} = 5$ diopters?

Repeat with the 4-inch lens. Is its focal length 10 cms. and its power $\frac{100}{10} = 10$ diopters?

Experiment No. 110. Power of spectacles. Measure in centimeters the focal length of your father's or mother's spectacles and calculate their power in diopters.

Experiment No. 111. Conjugate foci. Get the image of a candle as in Fig. 169, mark the position of the screen and the candle, and then exchange them. Do you again find an image, but of different size?

Repeat at different distances.

Two points so situated with respect to a converging lens that an object at either forms an image at the other are called **conjugate foci.** There are an infinite number of pairs of such points for each converging lens.

RELATION BETWEEN OBJECT AND IMAGE

If D_o is the distance of an object from a lens and D_i is the distance of its image from the lens, then $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F}$, where **F** is the focal length of the lens. This is one relation between the object and its image.

The magnification of an image is the number of times it is larger or smaller than the object, and you can always find it by dividing D_i by D_o; that is, the magnification $= D_i \div D_o$.

Experiment No. 112. Where is the image? Arrange the 4-inch lens with the candle 6 inches from it. Calculate where the image will be as follows:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F} \text{ or } \frac{1}{6} + \frac{1}{D_i} = \frac{1}{4} \text{ or } \frac{1}{D_i} = \frac{1}{4} - \frac{1}{6} = \frac{3}{12} - \frac{2}{12} = \frac{1}{12}$$

$\therefore$ D_i is 12. The image will be 12 inches from the lens. Try it. Now calculate and try where the image will be if the object is 5 inches, 7 inches, 8 inches, 12 inches, 20 inches from the lens, and so on.

Repeat with the 8-inch lens, using D_o greater than 8 inches.

Experiment No. 113. How big will the image be? Arrange the candle 6 inches from the 4-inch lens and the image will be at 12 inches, as you found above.

Now, since magnification $= D_i \div D_o$, it is $12 \div 6 = 2$, and the image will be 2 times as large as the object. Measure the height of the flame and of its image. Is the image 2 times as high as the flame? Try other distances and then the other lens.

MAGIC

Experiment No. 114. Cylindrical lens. Look at your finger through a tumbler of water. Does the tumbler of water act as a cylindrical lens and is your finger broad?

Experiment No. 115. Treble your money. Put a quarter in a tumbler half full of water, put a saucer over the tumbler, and invert both. Do you see a half dollar on the saucer and a quarter higher up? Why?

Experiment No. 116. Heat through ice. Place the concave mirror upside down on a sheet of clear ice ½ inch thick and let it melt into the ice. Do you get an ice lens? At noon, when the sun is hot, hold your hand at the focus of this lens. Is it hot?

Experiment No. 117. A spectrum from ice. Take a clear piece of ice, shave it to the shape of a prism, and hold it in sunlight. Do you get a beautiful spectrum?

OPTICAL INSTRUMENTS

FUN BY DAY OR NIGHT

A Magnifying Glass is simply a converging lens (Fig. 170) with the object **PQ** closer than the focus. The eye receives rays which are still diverging and sees the image **pq** enlarged. You have illustrated this above.

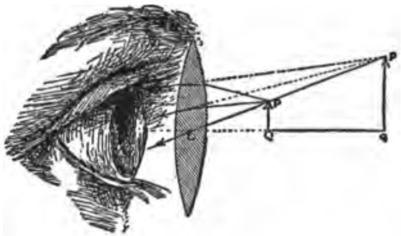


Fig. 170. A magnifying glass
From Lynde's Physics of the Household, published by The Macmillan Co.

The Astronomical Telescope (Fig. 171) consists of two converging lenses, or systems of lenses, connected by a long tube. The lens nearest the object is called the **objective,** and the lens nearest the eye, the **eyepiece.**

The objective (Fig. 172) forms a real inverted image **im** of the object **BO** inside the focus of the eyepiece. The eyepiece magnifies this, just as a magnifying glass does, and the eye sees the enlarged image **IM.**

When the telescope is focused on a distant object: the **dis-**

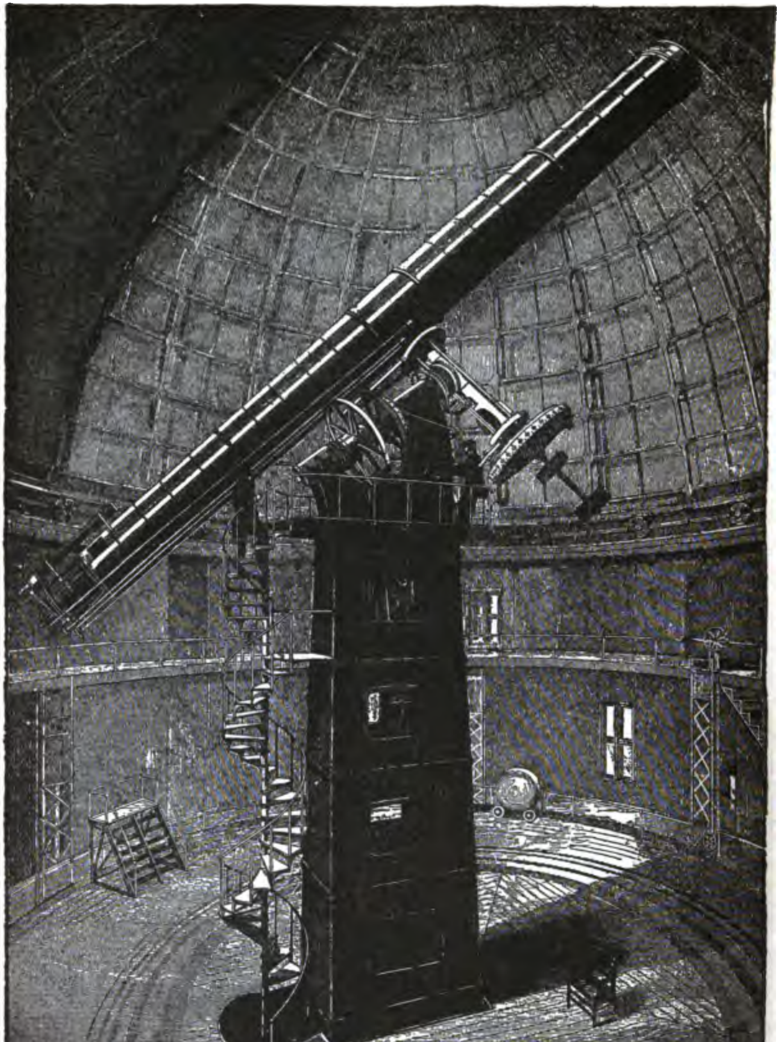


Fig. 171. Astronomical telescope at Lick Observatory
Courtesy of the Scientific American

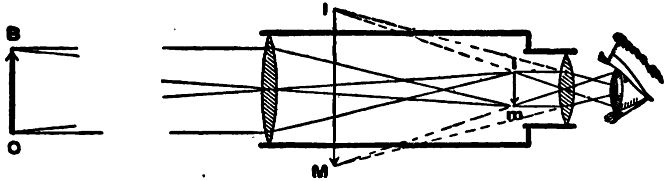


Fig. 172. How you see the image
From Lynde's Physics of the Household, published by The Macmillan Co.

tance between the lenses is equal to the **sum of their focal lengths**; and the **magnification** is equal to the **focal length of the objective divided by the focal length of the eyepiece.**

Terrestrial telescopes have, between the objective and eyepiece, other lenses which turn the image right side up.

Experiment No. 118. An astronomical telescope. Arrange the converging lenses on a piece of board (Fig. 173) and focus on a distant object.

Measure the distance between the lenses. Is it equal to the sum of their focal lengths, that is, $8 + 4 = 12$ inches?

Look at a distant object through the telescope with one eye and outside the telescope with the other eye. Is the magnification equal to focal length of objective ÷ focal length of eyepiece, that is, $8 \div 4 = 2$ times?

Fig. 173. You illustrate the telescope

Hold a piece of paper at the focus of the objective. Do you get an image?

Experiment No. 119. To make a telescope. Place 8-inch lens in ring hold-

Fig. 174. You make a telescope

er and wind dark wrapping paper around the holder to make a tube 10 inches long. Place 4-inch lens in the other ring holder and wind wrappingpaperaround the holder to make a tube 6 inches long. Slip the second tube into the first and your telescope is made (Fig. 174). Focus it on a distant object.

The Compound Microscope (Fig. 175) is the same in principle as the astronomical telescope, but the objective has very great power, that is, it has a very short focal length. The objective forms a real image, **im,** Fig. 176, of **BQ,** and the eyepiece forms the enlarged image **IM** of **im.**

Fig. 175. A compound microscope

The Opera Glass (Fig. 177) has a converging lens **C** for objective and a diverging lens **c** for eyepiece. The objective would form an inverted image **ab** of **AB,** but the eyepiece diverges the light and the eye sees the erect image **A'B'.** The ordinary opera glass consists of two such instruments;

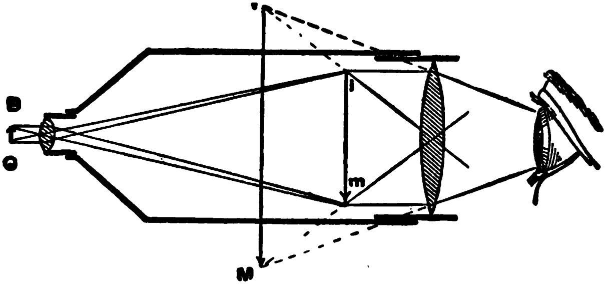


Fig. 176. Illustrating how images are formed in the microscope
From Lynde's Physics of the Household, published by The Macmillan Co.

they are shorter than the ordinary telescope and, therefore, more convenient.

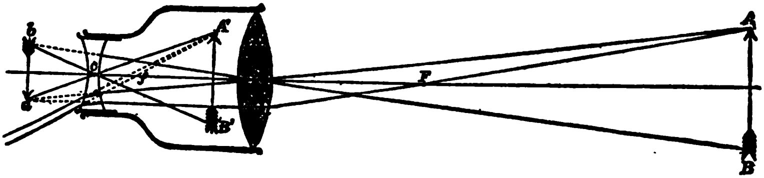


Fig. 177. How you see things in an opera glass
From Lynde's Physics of the Household, published by The Macmillan Co.

Experiment No. 120. An opera glass. Arrange the lenses on a piece of board as in Fig. 178. Focus on an object. Is the image erect and are the lenses closer together than in the telescope?

Fig. 178. You illustrate the opera glass

Experiment No. 121. To make an opera glass. Place 8-inch lens in ring holder and wind around it a tube of wrapping paper 3 inches long. Place

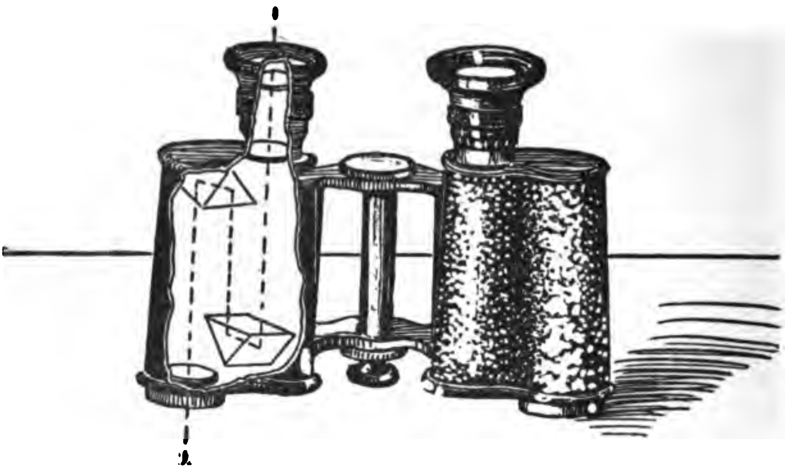


Fig. 179. Binoculars
Courtesy of the Scientific American

the diverging lens in the other ring holder and wind a tube 2 inches long. Insert the second tube in the first and your opera glass is made. Focus it on a distant object.

The Prism Binoculars (Fig. 179) are made with lenses similar to those in an astronomical telescope, but the light is reflected four times by means of glass prisms. This reflection makes the image erect and shortens the length of the tube.

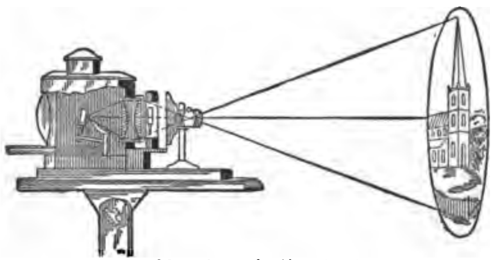


Fig. 180. A projecting lantern
From Lynde's Physics of the Household, published by The Macmillan Co.

The Projecting Lantern (Fig. 180) consists of a light-proof box, a source of bright light, a condensing lens, a lantern slide, and a projecting lens. The bright light, produced by electricity, acetylene, or, as

here, by a limelight, is converged on the lantern slide by the condensing lens and an image of the inverted slide is thrown on the screen by the projecting lens.

Fig. 181. You make a postcard lantern

The Postcard Lantern consists of a light-proof box, two electric lights which throw light on the postcard but not directly on the lens, a postcard slide, and a converging lens which throws an image of the postcard on the screen.

Experiment No. 122. Magic-lantern shows. Place 4-inch lens in ring holder in a hole in a large piece of cardboard, place a black book 6 inches from lens and a white screen 12 inches from lens on the other side, light the candles, and hold small objects against the book. Are their images thrown on the screen in natural colors and magnified twice?

Fig. 182. You hold a magic-lantern show

Experiment No. 123. To make a postcard lantern. You can have lots of fun with a lantern made as follows:

Get a cardboard or wooden box (Fig. 181) about 8″ × 6″ × 6″, put the 8-inch lens in ring holder and in a wrapping paper tube

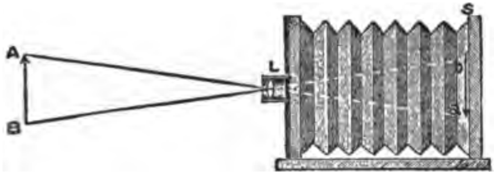


Fig. 183. A camera
From Lynde's Physics of the Household, published by The Macmillan Co.

4 inches long; put the tube into a hole in one side of the box and paint the opposite side of the box black. Place an electric light or oil lamp on each side of the postcard and close to it, and arrange two shades to prevent the direct light from falling on the lens. Hold a postcard, or other object, against the black end, focus the lens on a white screen about 2′ × 2′, and your lantern is finished. The illustration shows the lantern with the top and one side removed. The top should have a trapdoor at the rear end through which you can insert and remove the postcards. The audience is seated on the side of the screen away from the lantern.

Experiment No. 124. Fun at night. You can put on a magic-lantern show with oil lamps or electric lights as shown in Fig. 182. The doorway between two rooms is covered by two heavy curtains and the 8-inch lens in a ring holder is inserted in a hole in a piece of cardboard and pinned between the two curtains. A black book stands 10 inches from the lens, and is illuminated by two strong lamps; two screens prevent the direct light of the lamps from striking the lens. A white tissue paper or cloth screen, 2′ × 2′, is on the opposite side of the door 40 inches from the lens, the audience is beyond the screen, and if now you

Fig. 184. You illustrate the camera

hold postcards, drawings, and other small objects upside down against the book, the lens will throw erect and enlarged images on the screen, and your show is on.

The Photographic Camera is simply a light-proof box with a converging lens in one side and a plate holder in the other. The lens L (Fig. 183) throws an inverted image **ba** of the object **AB** on the plate **S**.

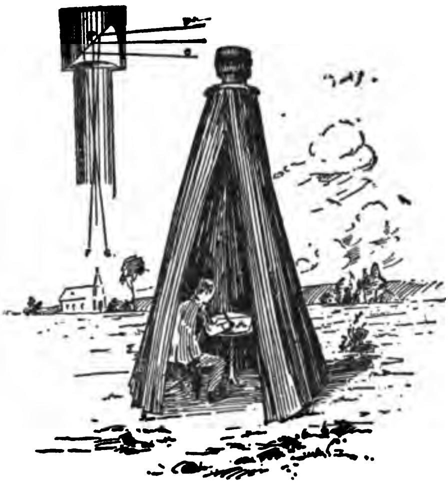


Fig. 185. The camera obscura

Experiment No. 125. To illustrate the camera. Put your converging lenses in turn in a ring holder, and put the holder in a hole in one end of a cardboard box (Fig. 184). Cover the box and your head with a dark cloth and move the screen back and forth until you get a picture.

Fig. 186. You make a camera obscura

The Camera Obscura (Fig. 185) has a combined lens and reflecting prism at the top which throws a picture down on the table in front of the artist.

Experiment No. 126. To make a camera ob-

Fig. 187. You make a submarine periscope

scura. Arrange the 8-inch lens, mirror, and box as in Fig. 186. Cover the front of the box and your head with a black cloth. Do you get a beautiful picture on the white paper at the bottom of the box?

Experiment No. 127. A moving-picture show. Use the camera obscura on a table outdoors or near a window and let two of you get under the black cloth and look at the picture, while two others go through funny antics outdoors about 30 feet from the camera. Do those under the cloth see a very funny moving-picture show? Change places and repeat.

Experiment No. 128. A submarine periscope. Arrange the apparatus as in Fig. 187 with the mirror at 45° at the top of a long cardboard tube and observe the paper under the black cloth. Do you get a fine picture on the paper?

This illustrates the construction of one type of submarine periscope.

The Stereoscope (Fig. 188) turns two pictures into one that **stands out.** The glasses are prismatic lenses placed edge to edge; they take light from the two pictures A_1B_1, A_2B_2, Fig. 189, and diverge it so that it appears to come from one pic-

Fig. 188. The stereoscope

ture **AB.** The pictures are taken in a stereoscopic camera, which is simply two cameras side by side and a short distance apart.

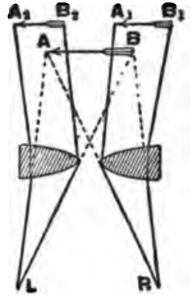


Fig. 189. How the stereoscope works
From Lynde's Physics of the Household, published by The Macmillan Co.

Your Eye (Fig. 190) has an outer horny membrane called the **cornea** and behind this a watery liquid called the **aqueous humor,** behind this a muscular lens called the **crystalline lens** and inside this another fluid called the **vitreous humor.** At the back is the nerve layer, the **retina,** which receives the sight impression, and behind the retina is a black coating which shuts out all light except that which comes through the lens. The colored part of the eye is the **iris** and the opening in the iris is the **pupil.** The iris contracts the size of the pupil in a strong light and enlarges it in a dim light.

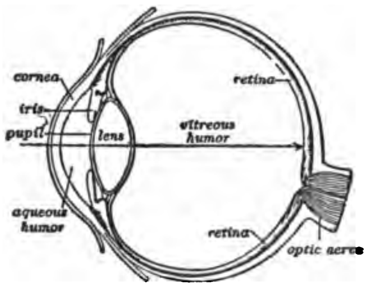


Fig. 190. Your eye
From Black and Davis' Practical Physics, published by The Macmillan Co.

The eye is very much like a camera, but there is one striking difference: the camera is focused by moving the lens back and forth; but the eye is focused by changing the shape of the lens and, therefore, its focal length. The muscles of the eye make the crystalline lens more convex when we view an object near at hand and less convex when we view one at a distance.

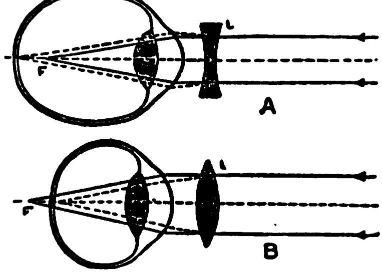


Fig. 191. The reason for the use of spectacles
From Lynde's Physics of the Household, published by The Macmillan Co.

Spectacles. The eyes of short-sighted people focus the light in front of the retina **F**, Fig. 191 **A**, and this difficulty is overcome by spectacles with diverging lenses, **L.**

The eyes of long-sighted people focus behind the retina **F**, Fig. 191 **B**, and this difficulty is corrected by spectacles with converging lenses, **L.**

Experiment No. 129. To look through your hand. Your two eyes look along converging lines when you look at any object,

Fig. 192. To make the bird enter the cage

and this leads to the following apparent magic. Roll a piece of paper into a tube, hold it beside your hand, look at your hand with one eye and through the tube with the other. Do you appear to see through your hand? Look through other things in this way.

Experiment No. 130. To put the bird into the cage. Draw a cage and a bird with centers about 2 inches apart on paper, stand a card on the line **AB** between them (Fig. 192), then look at

the cage with one eye and at the bird with the other. Does the bird enter the cage?

The Moving-Picture Machine (Fig. 193) throws 12 to 16 pictures on the screen each second and shuts off the light while one picture is changing to the next. The pictures are taken at the same intervals and differ very slightly one from the next (Fig. 194).

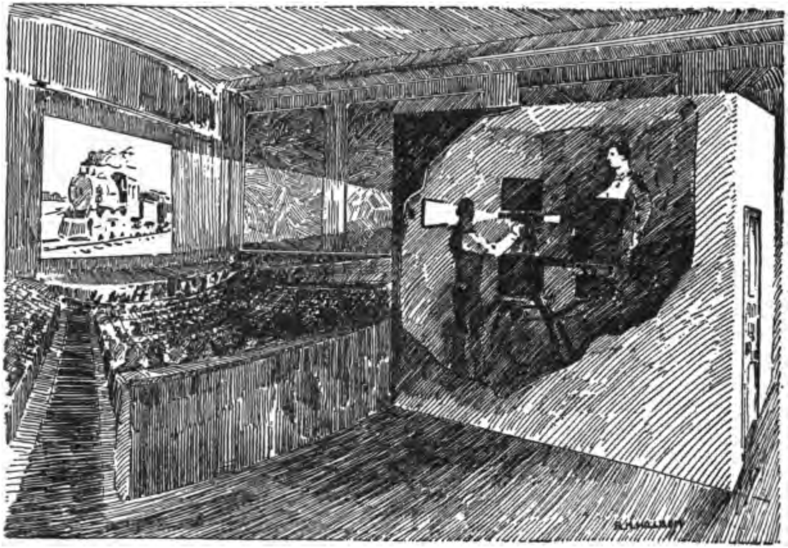


Fig. 193. A moving-picture machine

The "Why" of the Movies. The reason you see the pictures continuously and are not aware that the light has been shut off is that your eyes retain each picture for a short time after it has left the screen. You will now illustrate this.

Experiment No. 131. Circles of fire. Go into a dark room, light a match, blow it out but keep the live coal, and then wave

it in the air. Do you see circles of fire? You do, because your eye retains the impressions for some time.

Experiment No. 132. To put the bird into the cage. Draw a bird on one side of a piece of cardboard and a cage exactly opposite on the other side. Attach cords above and below and spin the cardboard. Does the bird appear to enter the cage? It does, because your eyes retain the pictures of the cage and bird for a short time.

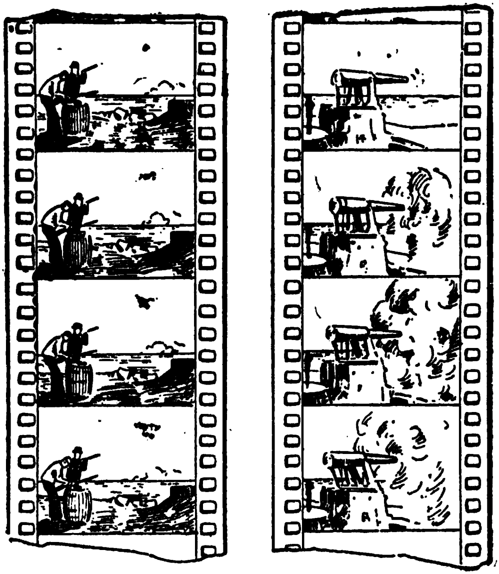


Fig. 194. The "why" of the movies